MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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VOLUME LXIII, PART 1.

THE GEOLOGY OF SIROHI STATE, RAJPUTANA. BY A. L. COULSON, M.Sc. (MELB.), D.I.C., F.G.S., *Assistant Superintendent, Geological Survey of India.* (With Plates 1 to 12.)

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CHAPTER I.

INTRODUCTION.

General.

This memoir embodies the results of work carried out by the author in the field seasons 1924-25, 1925-26, 1926-27 and 1930-31. The hiatus was caused by his appointment as Curator of the Geological Museum, Calcutta, and his subsequent absence upon leave. Mapping was done on the scale of one inch to the mile on the following sheets of the Central India and Rajputana Survey (old numbers are given first, the corresponding new numbers being in parenthesis): 75 (45 D/1 and 5), 76 (45 D/2 and 6), 77 (45 D/3 and 7), 93 (45 C/11 and 15), 94 (45 C/12 and 16), 95 (45 D/9 and 13), 96 (45 D/10 and 14), 97 (45 D/11 and 15), 117 (45 G/4 and 8), 118 (45 H/1 and 5), 119 (45 H/2 and 6), and 120 (45 H/3 and 7). Thus the whole of Sirohi is found on degree sheets (one inch to four miles) 45 C, 45 D, 45 G and 45 H.

Field work and map sheets.

It has been found convenient to refer to the one-inch map sheets throughout the memoir. To facilitate this reference, the accom-

panying text-figure (Fig. 1) has been inserted to show their notation and distribution. In this figure it will be noted that the longitude of the boundary between sheets 45 C and G and between 45 D and

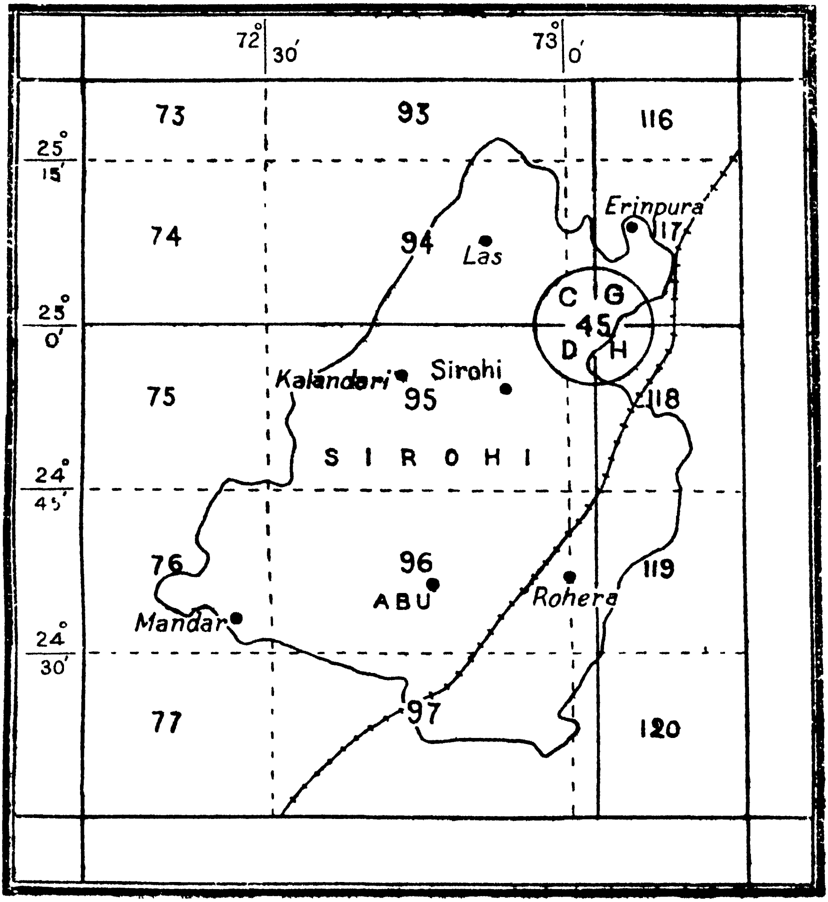

FIG. 1.—Sketch map showing the distribution and notation of the old one-inch sheets of the Central India and Rajputana Survey, and, also, of the new degree (four miles to the inch) sheets on which Sirohi State is found (the longitudes are those of the old one-inch sheets).

H differs from that dividing sheets 94—97 from sheets 117—120 respectively. The longitudes given on the map are those of the old one-inch sheets. For precise details of latitude and longitude, recourse may be made to the index provided at the end of the memoir. The figures for longitude given in that index have reference to those of the new quarter-inch sheets.

The geological survey of Sirohi was undertaken as part of the general re-survey of Rajputana and, also, in consequence of obligations entered upon with His Highness Maharajdhiraj Maharao Shri Sir Sarup Ram Singh Bahadur, K.C.S.I., of Sirohi.

Reason for survey.

Sirohi State is situated in the south-western part of Rajputana, roughly between the parallels of 24° 20′ and 25° 17′ north latitude and 72° 16′ and 73° 10′ east longitude; it has an area of 1,964 square miles[1] and is eleventh in size among the twenty states and chiefships of the Rajputana Agency. Its area is approximately that of the county of Northumberland. Sirohi is bounded on the north-east, north and west by Jodhpur; on the south by Palanpur and Danta; on the south-east by Idar; and on the east by Udaipur. Its greatest length from north to south is nearly sixty-four miles and its greatest width from east to west about fifty miles.

Area and position.

According to the census of February 26th, 1931,[2] the population of Sirohi State was 216,185 of whom 111,587 were males and 104,598 females. This is an increase of 29,546 or 15·8 per cent. over the census of 1921. The Mount Abu district had a population of 4,526 of whom 2,687 were males and 1,839 females. The State is named after its capital Sirohi, besides which there are only four towns, Abu Road (Karari), Seoganj, Abu and Erinpura Cantonment. Large villages include Kalandari, Mandar (Madar), Pindwara and Rohera. According to Tod, in his 'Travels in Western India', the name Sirohi may be derived from its position at the head (*sir*) of the desert (*rohi*).[3]

Population.

Physiography.

The chief physiographical feature of the State is the range of hills extending from near Erinpura in the north to past Abu in the south. The *massif* of Abu culminates in Guru Sikkar, 5,650 feet above sea-level, and is separated by a narrow valley on the north from the hills running N. N. E. to Erinpura. The general level of Abu hill station is only about 4,000 feet, but rising sheer from the plains on the east and west, the Abu *massif* is an impressive sight. Con-

Mount Abu-Erinpura range.

[1] This figure includes the Abu district of six square miles which is leased to the Government of India.
[2] *Gazette of India*, (21st March, 1931).
[3] Rajputana Gazetteer, III A, p. 229, (1909).

sidered as an entity, the Abu-Erinpura range divides the State into two not very unequal parts which may be termed the eastern and western parts. This central range of hills has hindered the development of the State from an economic standpoint. Thus whilst the eastern part has had easy access to the railway line running from Ajmer to Ahmedabad, with the stations of Pindwara, Rohera, Banas, Abu Road, etc., the western part, containing Sirohi town, Kalandari, Anadra, etc., was, until recently, joined with the railway by but two bullock-cart tracks.

Roads.

The Durbar, however, has practically completed the construction of a fine motor road from Sirohi to Pindwara, its nearest railway station, and this should greatly assist the development of the western part of the State. Before the advent of the railway, the western part was better provided with means of transport, inasmuch as the main military road from Ajmer to Ahmedabad passed through this region. This road, however, has been allowed to fall into disuse.

Other good roads which may be mentioned are those from Abu Road to Abu, and from Abu Road to Amba Mata temple in Danta State. The former is a fine piece of engineering and rises in some 16 miles from 857 feet above sea-level at Abu Road to 4,000 feet at the hill station.

Watersheds.

Both the eastern and western parts of Sirohi are intersected by numerous watercourses, which become torrents of greater or lesser volume in the rainy season, but which are dry during the greater part of the year. These streams discharge into the Luni and western Banas river. On the western side of the Abu-Erinpura range, most of the streams north of 24° 45′ flow northwards; those south of this latitude flow to the south. On the eastern side of the Abu-Erinpura range, the streams north of about 24° 53′ flow northwards, those to the south of this latitude flowing to the south. Accordingly, though the main physiographical feature is the N. N. E.-trending Abu-Erinpura range, the main watershed of the State trends approximately east and west.

Hills.

The 'Aravalli' hills, using the term in its physiographic sense, form a wall upon the eastern frontier of the state. Other important hills are Nandwar (3,277 feet) in the west (sheets 76 and 96) and Jairaj (3,575 feet) in the south-west (sheet 97). As these rise sheer from the plains, they

form impressive masses. The reader may be referred to the text for frequent mention of other hills, less important physiographically, but more important geologically.

Banas river.

The chief river in the State is the Western Banas which, rising on the eastern flanks of the hills east of Sirohi, flows for some 50 miles in the valley between Abu and the 'Aravalli' hills till it enters Palanpur near Mawal; it eventually loses itself in the sand at the head of the Rann of Cutch. Its most important tributary in Sirohi is the Sukli (Sipur) which has two branches, the western and the eastern. The former rises in the hills near Dantrai (sheet 96); the latter comes from the Sanwara hills (sheet 96) and the north-western slopes of Abu.

Tributaries of the Luni.

The most important of the north-flowing streams are the Krishnauti, Khari, Kachnauli and the Kapalganga rivers, all of which are eventually incorporated in the Luni.

Climate, Flora and Fauna.

Climate.

The climate of the plains is dry and the cold season, though short, is very agreeable. The average annual rainfall at Sirohi is only about 20 inches, nearly all of which falls during the short rainy season. The mean temperature at the town of Sirohi is about 84°F. Abu is the hill station for Rajputana and enjoys a much more equable climate than the plains. Its average rainfall is about 57 inches and mean temperature about 69° F.

Flora.

A considerable portion of the State is covered with trees and bush jungle; there are also several large grass reserves. Near villages, such trees as *nim* (*Azadirachta indica*), *pipal* (*Ficus religiosa*), *gular* (*F. glomerata*), banyan or *bar* (*F. bengalensis*), *ber* (*Zizyphus jujuba*), mango (*Mangifera indica*) and the tamarind are common. The bush jungle varies according to the nature of the ground. The *khair* (*Acacia catechu*), *dhao* (*Anogeissus latifolia*) and *thor* (*Euphorbia neriifolia* and *E. royleana*) are commonest on rocky ground. On sandy and alluvial country, *anwal* or *awal* (*Cassia auriculata*), the bark of which is gathered and sent to the tanneries at Cawnpore, *ak* or *akra* (*Calotropis procera*, the flowering shrub of the desert), *dhak* or *palas* (*Butea frondosa*, the 'Flame of the Forest'), *khejra* (*Prosopis*

spicigera), *babul* or *kikar* (*Acacia arabica*), *jhal* or *pilu* (*Salvadora persica* and *S. oleiodes*), *karel* (*Capparis aphylla*) and *ber* (*Zizyphus nummularia*) are found throughout the State.

The slopes of the higher hills, and of Abu especially, support a great variety of trees and shrubs with many species and genera. Full details concerning these will be found in the Rajputana Gazetteer.[1]

Fauna.

The fauna is varied but not very plentiful. Of big game, panther and bear are still shot in fair quantity. There are large numbers of *chikara* (Indian gazelle) with fewer *nilgai* (blue bull) and black buck. Wild dogs were not observed but jackal, foxes and hyæna abound. Recently wolves have made an appearance in the north-western part of the State.

As regards small game, several varieties of partridge, sand grouse and quail and numerous hare are the commonest. Jungle fowl are rare except on the slopes of Mount Abu. There are few large expanses of water and the evaporation is so large that most of the 'tanks' dry up at the end of the cold weather. Accordingly duck, teal and snipe are rare.

The *Girasias*, who inhabit the hilly country towards the Udaipur frontier, are great hunters and practically every man carries a bow and arrows; guns of varying antiquity are numerous amongst the inhabitants of the plains west of Abu. Accordingly it is not to be wondered at that game is relatively scarce in the State.

Previous Workers and Records.

C. A. Hacket, 1887-88.

In the field season, 1887-88, C. A. Hacket worked on the western side of the Aravalli range including portions of sheets 74, 75, 93, 94, 95, 96 and 97. Nothing with regard to this work has been published except a brief note stating that little further way had been made towards a solution of the geology of that region.[2]

The following is an extract from his progress report for 1887-88, his last season in the field :—

'The rocks within the range that is east of Mt. Abu have already been fully described. They consist of slates, limestones and quartzites intercalated with bands of more highly metamorphosed rocks in the form of gneiss. I could never separate these bands of gneiss from the less altered slates and limestones; in fact

[1] III-A, pp. 285-286, (1909).
[2] *Rec. Geol. Surv. Ind.*, XXII, p. 5, (1889).

they appeared to alternate and to pass into each other. This metamorphism also extends up to the highest rocks in the section, *viz.*, the Delhi quartzite and has locally converted it into gneiss.

'But outside the range, that is west of Mt. Abu, ——— the metamorphism appears to have been much more intense and only a few unimportant bands of the recognizable gneiss beds of the Aravali series are met with.

'The slates and limestone mixed with the gneiss to near the Abu road station about four miles east of the mountain, but west of that occurs a wide spread of gneiss with only an occasional band of limestone in the form of marble mixed with it.

'Mt. Abu has always been described as an isolated hill, but this is hardly correct as it forms part of a wide range of gneiss, divided it is true, by narrow passes. This band of elevated, highly porphyritic gneiss is widest at Mt. Abu being there 8 to 9 miles in width, it extends in a S. S. W. direction ——— beyond Sirohee a distance of nearly 50 miles.———

'The gneiss of this range is very felspathic and highly porphyritic crystals of felspar of 3 or 4 inches in length are not uncommon.

'——— In sheet No. 75, the gneiss extends half-way across the sheet, when a large spread of Malani beds comes in and west of which the whole country is covered by sand and not a rock seen. Some of the wells here are at least 200 feet deep all in sand from top to bottom.

'In sheet No. 74 ——— even fewer rocks are exposed and that only on the eastern side and only occupy one large group of hills and several small hills. They are all formed of gneiss similar to that of Mt. Abu.

'The only other rocks seen in the area N. of Mt. Abu are the Malani beds. Those beds were first described by Mr. W. Blanford as occurring in Malani and at Jodhpoor. I have seen those at Jodhpoor and when I came to this area I was so struck with the similarity of the two that I do not doubt that these are the Malani beds.'

R. D. Oldham, 1893.

In his 'Manual of the Geology of India', Oldham notes[1] that 'the gneiss of Mount Abu and its neighbourhood is said to be highly felspathic, massive, and crystalline, but occasionally a few schistose bands occur'.

F. C. Hughes and T. La Touche, 1897 and 1898.

A find of copper and gold was reported by Captain F. C. Hughes of the Erinpura Irregular Force near the village of Rohera. The place had evidently been worked to a considerable extent for copper in ancient times according to La Touche.[2] The old mine was filled with debris and was not excavated to a sufficient depth at the time of La Touche's visit to enable him to judge of the extent of the deposit. He stated the gold occurred in a pyritous schist associated with copper-bearing schists, but did not appear to exist in workable quantity.

[1] 2nd Edn., p. 40, (1893).
[2] *Gen. Rep. Geol. Surv. Ind.*, 1898-99, p. 45, (1899).

Upon the arrival of the author in Sirohi, he was given a copy of what were said to be the observations of Captain (later Colonel) F. C. Hughes in his report to the Resident, Western Rajputana, on the mineral products of Sirohi State. It is not proposed to quote these observations as the author has been unable to obtain the original report.

Rajputana Gazetteer, 1909.

The following short account of the geology of Sirohi appears in the Rajputana Gazetteer :—[1]

'The whole of Sirohi is occupied by schists and gneisses belonging to the Aravalli system, traversed by dykes of granite. Mount Abu is formed of a highly felspathic, massive and crystalline gneiss with a few schistose beds. Traces of gold were found in some ferruginous bands of quartzose schist near Rohera railway station in 1897, and the remains of old workings, which do not appear to have been more than prospecting trenches, are to be seen in the neighbourhood.'

The same gazetteer contains the following account of the minerals found in the State :—[2]

'The minerals of the State are unimportant. Traces of gold were found by Major Hughes (of the 43rd Erinpura Regiment) near Rohera in 1897, and according to tradition, a copper mine was formerly worked in the hills above the town of Sirohi. The marble of which the Jain temples at Abu are built is said to have come from near the village of Jhariwao on the south-eastern frontier. Limestone is quarried at several places, notably at Selwara (west of Anadra), Morthala (near Abu Road), and in the vicinity of Sirohi, and mica has been found in large quantities near Deldar in the south-east. Good bricks can be made from the stiff clay soil formed in the valleys on Abu by the crumbled felspar, but the general absence of limestone is a serious inconvenience; the granite of the hill is used to a considerable extent for building purposes, but, as it breaks very irregularly in quarrying and is extremely hard, it is expensive to work and not well-adapted for masonry. Fragments of mica are met with in different parts of Abu, and fine specimens of rock-crystal are occasionally picked up. Lastly the compact blue slate, on which the mass of granite rests, crops up here and there on the hill, and is useful for flooring barracks and other purposes where a strong durable stone is required.'

A. L. Coulson.

The progress of the author's work in Sirohi has been noticed in the General Reports of the Geological Survey of India for the years 1925,[3] 1926,[4] 1927,[5] and 1931.[6] With new evidence furnished by other parts of the State, it has been found necessary to modify certain of the views expressed

[1] III A, p. 232, (1909).
[2] *Op. cit.*, p. 265, (1909).
[3] *Rec. Geol. Surv. Ind.*, LIX, pp. 102-104, (1927).
[4] *Op. cit.*, LX, pp. 112-115, (1928).
[5] *Op. cit.*, LXI, pp. 131-132, (1929).
[6] *Op. cit.*, LXVI, pp. 135-137, (1932).

in the earlier progress reports. Accordingly this memoir may be taken as expressing the author's final views as regards the correlation and age of the various rocks found in Sirohi.

The author has published three papers of mineralogical interest concerning Sirohi rocks and minerals, *viz.*, 'On a Titaniferous Augite from Chandrawati, Sirohi State, Rajputana';[1] 'On the Zoning and Difference in Composition of Twinned Plagioclase Felspars in certain rocks from Sirohi State, Rajputana';[2] and 'The Albite-Ala B Twinning of Plagioclase Felspars in certain acidic rocks from Sirohi State, Rajputana'.[3] Relevant reference to these papers will be made in the text of this memoir.

A. M. Heron.

Dr. A. M. Heron, Superintendent-in Charge of the Rajputana Party of the Geological Survey of India, paid visits of inspection to Sirohi State as follows:– December, 1926, to the neighbourhood of Sindret (sheet 95) and to Abu; in January, 1929, to the frontier region of Sirohi and Udaipur in the neighbourhood of Waloria and Bori ki Bhuj (sheet 119); in March, 1930, to the Waloria (sheet 119), Sindret (sheet 95) and Undwaria (sheet 96) areas; and finally, in April, 1931, to Abu and the frontier district with Udaipur, east of Pindwara (sheet 118). During his last visit, Dr. Heron was kind enough to join up the author's work in Sirohi with that of Dr. P. K. Ghosh in Jodhpur to the north, and his own and Mr. J. B. Auden's work in Udaipur to the east. The author is in possession of copies of Dr. Heron's notes concerning his 1929 and 1930 visits and, where quoted, due acknowledgment has been made in the text.

Workers in Contiguous Areas.

C. A. Hacket.

Hacket mapped the rocks across the border in Udaipur as Aravalli. The area to the east of Erinpura is shown on his map of the 'Arvali Region, Central and Eastern',[4] but that to the south of Erinpura is uncoloured.

T. H. D. La Touche.

Frequent reference will be made in the text to La Touche's able description of the area to the north and north-west of Sirohi State.[5] In his map of Western Rajputana accompanying his memoir, La Touche has col-

[1] *Rec. Geol. Surv. Ind.*, LXIII, pp. 448-450, (1930).
[2] *Op. cit.*, LXV, pp. 163-172, (1931).
[3] *Op. cit.*, LXV, pp. 173-184, (1931).
[4] *Rec. Geol. Surv. Ind.*, XIV, (1881).
[5] *Mem. Geol. Surv. Ind.*, XXXV, pp. 1-116, (1902).

oured the hills around Ban (sheet 94) as 'Aravalli schists and quartzites' and 'Erinpura granite'; those around Gol on the same sheet are shown as Aravallis. He states in his text that he did not visit the hills in question as they were mapped by Hacket. However, according to the originals of his one-inch maps stored in the office of the Geological Survey of India, Hacket mapped the northern part of the Las hills as rhyolite, and the southern region as gneiss (=Erinpura granite); the hills near Gol are shown as rhyolite. This is in accordance with his progress report quoted above.

C. S. Middlemiss.

Middlemiss has described the geology of Idar State, which lies to the south-east of Sirohi.[1] Constant reference will be made to this important work.

N. L. Sharma.

Mr. Sharma has recently published a preliminary note on the geology of Danta State[2] and it is understood that a larger paper will follow shortly.

A. M. Heron, J. B. Auden, P. K. Ghosh and B. C. Gupta.

The Rajputana party of the Geological Survey of India, under the active superintendence of Dr. Heron, has been mapping in the adjoining states of Jodhpur and Udaipur. Every effort has been made to correlate the Sirohi rocks with those in other parts of Rajputana, and the reader is referred to the text for mention of individual workers. Dr. Heron is at present compiling the results of his many years' work in the central parts of Rajputana. Frequent reference will be made to his previous papers on Rajputana, the chief of which is his memoir on the geology of North-Eastern Rajputana and its adjacent districts.[3]

Acknowledgments.

A. M. Heron.

The author wishes to record his sincerest thanks to Dr. A. M. Heron, Superintendent-in-Charge of the Rajputana party of the Geological Survey of India, of which party the author was a member. He has freely discussed with him personally and by correspondence the problems arising during the elucidation of the geology of Sirohi and Dr. Heron never failed to co-operate in this connection. Throughout the text of this memoir, the author has endeavoured to give due acknowledgment to Dr. Heron's views; but the value of personal discussion of problems as they arise cannot be overestimated.

[1] *Mem. Geol. Surv. Ind.*, XLIV, Pt. 1, pp. 1-166, (1921).
[2] *Q. J. Geol. Min. Met. Soc. Ind.*, III, pp. 17-28, (1931).
[3] *Mem. Geol. Surv. Ind.*, XLV, pp. 1-128, (1917).

Study leave.

Whilst on study leave on the Continent, the author had the privilege of working at certain of his Sirohi specimens in the mineralogical laboratory of the National Museum of Natural History, Paris, and in the mineralogical and petrographical institutes of the Universities of Basel and Bonn. He wishes to record his gratitude to Professor A. Lacroix and his staff, to Professor M. Reinhard, and to Professor R. Brauns and Dr. K. Chudoba for their constant interest during his visits to these institutions.

CHAPTER II.

ROCK FORMATIONS PRESENT AND SUMMARISED HISTORY OF THE AREA.

List of Formations.

The following is a list of the rock formations found in Sirohi State :—

Post-Tertiary and Recent :—Wind-blown sand, talus, alluvium, and conglomerates, etc.

Post-Malani basic intrusives (? Purana) :—Dolerites.

Malani system (? Purana) :—Idar granite, porphyries, rhyolites and dellenites.

Post-Erinpura-granite but pre-Malani basic intrusives :—Dolerites, epidiorites, gabbros, pyroxenites, picrites, basalts and sodalite-syenites.

Post-Delhi but pre-Malani granitic intrusives :—Erinpura granite and accompanying quartz-reefs, pegmatites, and aplites.

Delhi and post-Delhi but pre-Erinpura-granite, basic intrusives :—Dolerites, epidiorites, amphibolites, hornblende- and actinotite-schists.

Delhi System :—*Ajabgarh series*—

3. Limestones and calc-rocks, with associated basic rocks.
2. Mica-schists and thin quartzites, with abundant associated basic rocks.
1. Quartzites.

Unconformity.

Aravalli System (Archæan) :—Mica-schists, phyllites, shales, crystalline limestones, quartzites, grits and conglomerates, with ? contemporaneous tuffs and lavas.

Summarised History of the Area.

Those seeking palæontological records must turn elsewhere than to Sirohi, for in all the rock formations, no single trace of a fossil organism has been noted. Nor is this to be wondered at when it is realised that if the

No fossils found.

recent alluvium and sand be excluded, the stratified rocks cropping out in the State belong to the Archæan and Purana, the former being laid down before the dawn of life on the earth, and the latter formed when life perhaps consisted merely of soft-bodied invertebrates.

Whilst the correlation of the Aravallis and Delhis with their representatives in other parts of Rajputana and elsewhere is important, the chief feature of interest in the geology of Sirohi lies with the igneous rocks contemporaneous with, intrusive into, and extruded over the Aravallis and Delhis. These, roughly, are of two kinds, acidic and basic.

Igneous rocks of chief interest.

Igneous activity of basic character occurred during Aravalli times, and basic tuffs and lavas are interbedded with the earlier members of this system. The later members of the Aravallis seem free from contemporaneous igneous rocks.

First basic phase :— Aravalli.

There is no positive evidence in Sirohi of the intrusion of igneous rocks, acidic or basic, at the close of the Aravalli period when these rocks were uplifted and folded, or during the time interval that elapsed before the laying down of the Delhis upon the eroded edges of the Aravallis. Rocks of the Raialo system and the lower members of the Delhis, comprising the Alwar series, Kushalgarh limestone and Hornstone Breccia, are not found in the State.

Unconformity between Aravallis and Delhis.

The Delhis found in Sirohi have been ascribed to the Ajabgarh series. Basic igneous activity was renewed either during the laying down of these rocks or shortly after, constituting the second basic phase. If these rocks are not contemporaneous with the Delhis, they are all at least pre-Erinpura-granite. They have been affected by the folding movements and metamorphism immediately preceding the intrusion of the Erinpura granite and so are older than the granite.

Second basic phase :— Delhi or post-Delhi but pre-Erinpura-granite.

Granite rocks were next intruded into all the above rocks, this acidic phase being of gigantic magnitude. The Erinpura granite, with its accompanying aplites and pegmatites, corresponds to the post-Delhi granites of other parts of Rajputana, and is by far the most important rock in Sirohi State. There is no evidence of the magma

First acidic phase :— Erinpura granite.

of this granite ever reaching the surface, though, of course, it would be extremely fortuitous were such evidence to persist throughout the erosion period that has elapsed since its intrusion. The superincumbent rocks, however, were greatly heated, shattered and metamorphosed, and faulting occurred. The roof, however, did not give way and the magma generally cooled with extreme slowness.

Third basic phase :— post-Erinpura-granite but pre-Malani.

Another series of basic rocks was now intruded, this phase being especially active in the western part of the State. These rocks are dolerites or basalts, and are found in large dykes, and also in fine veins, intruding the Erinpura granite.

Second acidic phase :— Malani.

There followed another intrusion of acidic material on an immense scale, almost comparable with the Erinpura granite. The chief rock is the Idar granite, but its hypabyssal and volcanic representatives are scarcely less important petrologically. The intrusion of this Idar granite was accompanied by faulting.

Fourth basic phase :— post-Malani

The basic rocks ended the struggle for ascendancy with their fourth phase, certain basic rocks definitely intruding the Malani rhyolites and porphyries. This phase, however, was of very minor importance compared with the preceding phases. The area has been quietly eroded from the time of intrusion of these post-Malani basic rocks to the present day.

Brief summary.

Such in brief is the history of Sirohi, a series of intrusions of basic and acidic material into two fundamental series and into each of the preceding intrusions, there being at least four basic and two acidic phases.

Mapping.

Before proceeding to the detailed description of the rocks listed at the beginning of this chapter, the following remarks concerning the mapping may not be inappropriate.

The main map accompanying this memoir (Plate 12) has been published on the scale of one inch to four miles, a quarter of that used in the field. The colours adopted for the legend have been chosen in conformity with those on maps of Rajputana previously published or to be published in the future.

It will have been gathered that with basic rocks ascribed to four different ages, it is difficult in most places in the field to say with certainty to which of the four phases certain rocks belong-

General appearance is a useful criterion, but this is insufficient in by far the greater number of cases. Accordingly the outcrops of most of the basic rocks have been shown by dots, a method admittedly imperfect but considered to be of more value than any scheme of a definiteness which may be unsafe to apply.

Outcrops of the pegmatite which accompanied the Erinpura granite have not been shown on Plate 12 though they were mapped on the one-inch sheets.

CHAPTER III.

ARAVALLI SYSTEM.

Descriptive Subdivisions.

Position and extent.

Rocks belonging to the Aravalli system crop out in the western part of the State, approximately north-west of an imaginary line joining Erinpura Road railway station (sheet 117) with Vasra (sheet 97). They do not, however, form the only rocks cropping out in this part of the State. They occur in the south-eastern corner of sheet 76 and in the north eastern corner of sheet 77, stretching from there into sheets 96 and 97. Most of the western part of sheet 95 is covered with Erinpura granite, but there are isolated and continuous tracts of Aravallis in the central part of this sheet, in the south-eastern corner of sheet 94, and in the south-western corner of sheet 117.

Subdivision for descriptive purposes.

For the purposes of description, the Aravalli outcrops may be considered as a series of roof-masses of greater or lesser magnitude, set in Erinpura granite, which have escaped being assimilated or being stoped away by the granite. Enumerating them from east to west, they fall into the following tracts or areas :—

1. Sirohi-Erinpura tract, with isolated and connected masses of Aravallis stretching from Erinpura in the north-east (sheet 117), south-west to south of Sirohi town (sheet 95).
2. Sindret-Undwaria tract, comprising the oldest members of the Aravallis and stretching from Pardi (sheet 95) S. S. W. to south of Undwaria (sheet 96).
3. Dodia-Malgam tract, extending S. S. W. from near Dodia (sheet 95), through Balda and Ronella, to Malgam (sheet 96), where this tract joins with the sixth subdivision below.
4. Dantrai-Kankodara remnants, consisting of isolated roof-masses of Aravallis of greater or lesser size, chiefly along the direction (south-west) of an imaginary line joining Kankodara (sheet 95) with Dantrai (sheet 96).

5. Motagaun-Haliwara remnants, similar to the above, but along a line running south-west from west of Motagaun (sheet 95) to Haliwara (sheet 95).
6. Anadra-Mandar area, a large spread of Aravallis cropping out on sheets 76, 77, 96 and 97.

Strike and metamorphism.

The general strike of the Aravallis in the State corresponds to that of other parts of Rajputana, *i.e.*, approximately N. E.–S. W., but there are local changes in direction which will be detailed in the description of the various subdivisions. In general, also, the severity of the metamorphic imprint which these rocks bear increases as one passes south-westwards along the strike, due account being taken of the size of the outcrops in question.

Sindret-Undwaria Tract.

Lowest members of the Aravallis :—Sindret-Undwaria tract.

One may conveniently commence the description of the exposures by a description of the rocks occurring in the Sindret-Undwaria tract, containing, as this does, the lowest members of the system. The rocks themselves comprise conglomerates, grits, shales, phyllites thin quartzites, and slightly calcareous shales, with interbedded basalts and tuffs. Isolated outcrops are found in the alluvium to the north-west of Sirohi town (sheet 95), but the main outcrop commences between Goelli and Pardi and trends, at first, due southwards. Here the general structure appears to be in the nature of a dissected anticline, the conglomerate cropping out in the bed of the Kameri stream. Proceeding southwards, the lateral extent of outcrop is reduced from two miles to one mile near Sindret, the mass of Malani rhyolites, dellenites and porphyries constituting Pamta Hill forming a ridge in the centre of the tract.

Towards Mirpur and Balda (sheet 95), the strike changes to a more S. S. W. direction and the rocks become more metamorphosed. Near Sirori (sheet 96), the lateral width of outcrop has increased to some six miles.

Sindret conglomerate and grits.

As far as can be gathered from the field evidence, the conglomerate already mentioned appears to be the lowest member of the Aravallis in Sirohi, and as such is worthy of detailed description. The first outcrop is found two miles E. S. E. of Pardi in the bed of the

Kameri stream, its dip being some 30° to the west and the rock (42/283)[1] being a coarse, easily weathered, gritty conglomerate. What is presumably the same conglomerate is found lying horizontally in the bed of the same stream, some 2½ miles south-east of Pardi, and with varying dips in the tributary of the Kameri, just west and north-west of Khomal. A quarter of a mile south-east of the horizontally bedded conglomerate is a series of grits and shales with thin quartzites. These generally have a low easterly dip, the grits showing current-bedding. A section of a grit (42/290, 21198) shows fragments of shales, granite and quartzite with quartz, felspars, micas, iron-ore and ? altered garnets.

The Sindret conglomerate forms the bulk of the hill running north from the village of Sindret. Its outcrop here can be seen in Figure 9 (p. 116), a special text-figure drawn in connection with the description of the Malani rocks of the Sindret area. In its northernmost extension, it dips vertically, striking N.–S. The dip, however, lessens as one proceeds south, being first some 20°, and then 40°, to the west. The structure of this region is complicated.

Sindret Hill.

The conglomerate here consists of large pebbles of quartz-pegmatite, quartzites, phyllitic mica-schists, quartz-schists and black shales. No pebbles of granite, gneiss nor basic igneous rocks were noticed. Abundant quartz, muscovite, felspar, biotite and fragments of shale were seen in a section of the matrix of the conglomerate (21211). The pegmatite pebbles are derived undoubtedly from some pre-Aravalli acid derivative of some equivalent of the Bundelkhand gneiss or the gneissic complex.[2] A section (21212) of the black shale is uniformative, but presumably these representatives of stratified rocks belong to yet older members of the Aravallis or even pre-Aravalli rocks, which have suffered erosion before the laying down the Aravallis of Sirohi. The pebbles do not appear to have been transported any great distance. It might be emphasised here that the Sindret conglomerate is not thought to be necessarily the basal Aravalli conglomerate, but merely a local one, of no great extent and variable in nature, which appears to be the lowest member of the Aravallis occurring in Sirohi.

[1] Numbers such as 42/283 refer to the registered number of the specimen in the rock collection of the Geological Survey of India; numbers such as 21198 refer to the registered number of the thin section in the collection of the same Department.

[2] *Rec. Geol. Surv. Ind.*, LXV, p. 139 (1931).

The Sindret conglomerate near Sindret is intruded by the Erinpura granite and its pegmatite and also by the Malani suite of rocks.

Just south of the Sindret Hill is a mass of conglomerate, surrounded by Erinpura granite. There are also a few isolated masses among the basic rocks to the south-west of Sindret. Three exposures of conglomerate with vertical dips were noted west of Pamta Hill, approximately one mile south-east of Mamauh. It is possible that these also belong to the Sindret conglomerate, their matrix (21207) being very similar.

Isolated outcrops of conglomerate.

Proceeding southwards, there is a break in the continuity of exposures, the next and most southerly mass being found some three miles south-east of Undwaria (sheet 96). The numerous specimens and slides of this outcrop (36/146, 17126; 36/147, 17127; 36/150, 17129; 36/153, 17131; 36/155, 17133) indicate the rock to be a conglomerate with a coarse, angular, quartzose, gritty matrix. A definite banding of quartz and felspar pebbles of varying sizes can be seen in the field. Quartz, felspar and both micas are visible under the microscope and there is a fair amount of sphene and iron-ore in one section (17133). The specimens and sections suggest that the constituents of this metamorphic grit have not travelled any great distance to their final resting place.

Undwaria.

Certain thin beds of ferruginous shales appear to overlie the Sindret conglomerate and grits in some places. They were noted in the V-shaped tongue between the northernmost extremity of the Sindret conglomerate in the Sindret Hill and the quartz-porphyry forming the backbone of the hill (*see* Fig. 9). Here, as is natural in a crushed area, they are highly shattered and possess varying dips. Similar shales were noted at the base of the conglomerate hill, south-east of Undwaria. They are very similar in appearance to the thicker beds of ferruginous shales which occur higher up in the stratigraphical sequence.

Thin ferruginous shales.

Between the Sindret Hill and the Pamta Hill occurs an extremely interesting series of amygdaloidal basalts and tuffs, the exact age and relationships of which caused considerable trouble. These constitute what has been termed in a previous chapter the first basic phase (*see* p. 13). Just

Sindret basic rocks.

west and south-west of Sindret, they appear to abut against the thin, ferruginous shales above mentioned. Their dips cannot be made out in the valley itself, but on the eastern flanks of the Pamta hill, they dip westwards into the hill, usually at about 45°. Their outcrops cannot be followed continuously towards the north on account of alluvium, but near hill station 1,011 feet, they trend due north, dipping usually at a high angle to the west. Similar rocks are found on the extreme south-western flanks of the Pamta Hill, near Varela, and also near the conglomerate at Undwaria.

Contemporaneous age presumed.

It is often a matter of extreme difficulty to obtain conclusive field evidence of the contemporaneous formation of interbedded basaltic rocks. Definite evidence is wanting here, but the presumptive evidence of contemporaneity has been considered sufficient. This is strongest between Goelli and Pardi, where no signs of these basic rocks cutting across the general strike of the other members of the system were noted. It is realised that this alone is insufficient evidence of contemporaneity, as it does not exclude later sill injection ; but as will be seen, the rocks consist mainly of tuffs and basalts, the injection of the former of which appears to create difficulties not necessary on the assumption of contemporaneous age. Two thin quartzite beds, which can be traced continuously along their strike, form datum lines easily recognizable. One of these rises to form the hill station 1,011 feet and in the valley between it and the other band, and also between this second band and the river, occur tuffs and basalts intruded by quartz-epidote-pegmatite, Erinpura-granite in age (42/285, 21194). A section (21191) of a tuff, 1¾ miles E. S. E. of Pardi, shows a structure very similar to that of the rocks near Sindret.

Petrological examination of Sindret basic rocks.

Most of the Sindret basic rocks are best described as altered, amygdaloidal basalts, but they have not always suffered the same alteration.

Sections (17042 A and B) show a chloritised basalt, with abundant calcite in the groundmass. There is a little residual augite and a large amount of iron-ore, but the chief interest of the rock lies in the feslpars, two of which were determined by the Federov stage. In 17042 B, there is an excellent example of a 'right' Baveno twin of composition 70 per cent. An (*see* Plate 11, fig. 1); in 17042 A, the two individuals of a felspar lath, twinned according to the

Carlsbad rule, have compositions of 55 and 70 per cent. An.[1] Certain of the amygdaloidal basalts are palagonitised[2] and albitised. In a specimen from one mile south-west of Khomal (36/112, 17091), the individuals of two felspars, twinned according to the Carlsbad law, have compositions between 0 and 5-10 per cent. An. It was noted in one case that the individuals forming the Carlsbad twin had not 'turned' through 180° in the twinning formation. This slide also shows delessite and celadonite.[3]

In another amygdaloidal basalt from 1½ miles N. N. W. of Sindret (36/114, 17095), epidotisation has accompanied the palagonitisation and the felspars are greatly altered. There are what appeared to be possible pseudomorphs of delessite after olivine,[4] but delessite also lines the vesicles.

An epidotised basalt from one mile south-west of Khomal (36/113, 17094) is interesting on account of the radiating masses of epidote it contains in the amygdales. These crystals have a density of 3·233 at 16° C., determined by means of a mixture of ether and methylene iodide, using a Westphal balance. This is lower than the usual densities of epidote (3·32-3·49),[5] but is slightly higher than the density (3·21) of the colourless epidote from Terra del Fuego described by Lacroix.[6]

The pleochroism of this Khomal epidote is as follows:—

$\mathfrak{a}$ = light yellowish green,
$\mathfrak{b}$ = yellowish green,
$\mathfrak{c}$ = yellowish green.
Absorption :— $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

Its indices of refraction for sodium light are:—

$$\alpha_{Na} = 1{\cdot}732 \pm 0{\cdot}001$$
$$\beta_{Na} = 1{\cdot}747 \pm 0{\cdot}001$$
$$\gamma_{Na} = 1{\cdot}759 \pm 0{\cdot}001$$
$$\gamma - \alpha = 0{\cdot}027$$

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 171, (1931).
[2] L. L. Fermor, *op. cit.*, LX, pp. 420-422, (1928).
[3] L. L. Fermor, *op. cit.*, LVIII, pp. 137-147, (1926).
[4] L. L. Fermor, *op. cit.*, LVIII, p. 122, (1926).
[5] C. Hintze, 'Handbuch der Mineralogie', Leipzig, II, Pt. 1, p. 214, (1897).
[6] A. Lacroix, *Bull. Soc. Min. franç*, X, pp. 150-151, (1887). *See* also C. Dœlter, 'Handbuch der Mineralchemie', Dresden, II, Pt. 2, p. 835, (1917). The lowest recorded density of epidote is 3·04, for a specimen from Su Porro.

These differ slightly from those given by Larsen.[1] The mineral is negative. Actual measurements of the optic axial angle, using red light and correcting for the difference between the refractive index of the hemisphere (1·65) and that of the mineral[2] gave 2 V = 76°. Calculation by Bartalini's formula[3] from the above values of the indices gave 2 V = 83°.

Other minerals noted in the amygdales of this Khomal rock are quartz, calcite and ? celadonite.

A very fine-grained rock (42/295, 21203) was noted three-quarters of a mile S. S. E. of Angor. Its field relations suggest it to be possibly an interbedded basalt.

Two specimens were collected by Dr. A. M. Heron from the valley between Sindret and Pamta Hills. A section of the first (20904) is described by him as a tuff or greywacké. The other (20904) is an amygdaloidal basalt, with abundant calcite, palagonitic minerals and secondary quartz.

Rocks similar to these Sindret basalts and tuffs occur near the conglomerate, 2¾ miles E. S. E. of Undwaria. One specimen of basalt (36/152, 17130) shows a fair amount of epidote and palagonitic minerals. Efforts to measure the composition of the felspars by the Federov stage gave inconclusive results. Another specimen (36/156, 17134) shows the junction between a coarse heterogeneous tuff and one of the shales mentioned previously (*see* p. 19). On his visit to Sirohi in March, 1930, Dr. Heron noted a dark green (basic) amygdaloid near the top of the conglomerate ridge, but could not make out whether it was a lava interbedded with the conglomerate or a dyke or sill.

Thin quartzites.

Frequent mention has been made of thin quartzite beds in these lowest members of the Aravallis. They generally form ridges which rise to a small elevation over the neighbouring rocks and which sometimes can be traced a few miles along their strike. The best examples occur between Goelli and Pardi (sheet 95), but these end in the alluvium at the northernmost end of Pamta Hill, a mile or so E. N. E. of Angor. On the western side of same hill, east and south-east of Angor, other bands of these quartzites occur. Their general strike is N.–S. with a high westerly dip. Though of fair extent near Angor, they are

[1] E. S. Larsen, *Bull. U. S. Geol. Surv.*, 679, p. 268, (1921).

[2] F. E. Wright, 'The Methods of Petrographic-Microscopic Research', Washington, Pl. VII, (1911).

[3] F. Becke, 'Tschermak's Lehrbuch der Mineralogie', Vienna, p. 211, (1921).

generally only a few feet in thickness and appear to thin out when followed along their strike. It is probable that they are partly chemical in origin, siliceous solutions altering, replacing and cementing fine-grained shales.

Microscopic examination of these thin quartzites shows them to be very fine-grained and to contain a fair amount of fine calcite (42/284, 21192). Certain specimens (42/288, 21197; 42/289) from Angor can almost be termed cherts. Others (42/287, 21196) have a greenish appearance and are extremely fine-grained.

A thin band of quartzite crops out near the conglomerate outcrops, one mile S. S. E. of Mamauli.

A band of quartzite forms the ridge, 2½ miles south-east of Undwaria (sheet 96). This quartzite (36/138, 17119) is sedimentary in origin; it contains a few felspathic grains, and is much coarser grained than, and of a different nature from, the quartzites from Pardi and Angor.

A greenish quartzite (36/148, 17128), which resembles the Angor example mentioned above, occurs in the conglomerate hill, 2¾ miles E. S E. of Undwaria. This too is probably due to the silicification of fine-grained shales. It is quite local in extent.

Summary of lowest members.

The foregoing description of the lowest members of the Aravallis is of necessity brief. The oldest member is apparently a conglomerate with associated grits; but there is no evidence as to the nature of the rock upon which these were laid down. No exposures of the pre-Aravalli gneiss, noted by Dr. Heron to the north of the State, have been found in Sirohi.

The conglomerate and grits were succeeded by a series of thin ferruginous shales, then by basalts and tuffs, continued intermittently with the formation of further thin shales and quartzites. But after this period, it is impossible to give the stratigraphical sequence with any certainty owing to the imperfections of the geological record. Accordingly it is proposed to describe the other types met in the Sindret-Undwaria tract, and then to continue with a brief description of the other areas enumerated before (*see* p. 16). It must always be remembered that the Aravallis, except in certain areas, are intruded by acidic and basic rocks of different ages. The contemporaneous basic rocks at the base of the Aravallis have been described above, but it is obviously desirable to postpone the discussion of these later intrusive rocks.

It has already been noted that, broadly speaking, the metamorphic imprint possessed by the Aravallis in the Sindret-Undwaria tract generally increases in severity as one passes S. S. W. A large mass of ferruginous shales, with varying strikes and dips, crops out in the alluvium to form hill station 1,007 feet, north-east of Pardi (sheet 95). Similar shales are found W. N. W. of Goelli and south of Mirpur (sheet 95), where they dip south-east at 80°. North-west of Mirpur, less ferruginous shales are met with, dipping north-west at 80°. South-west of Mera, in the vicinity of the Pawara police station, definitely schistose types make their appearance; and these continue on sheet 96 to the south by Anadra and Pitapura. Further east, away from the Erinpura granite 'tongue' running down to Sirohi, the metamorphism is not so intense and phyllitic shales and phyllites are found. Proceeding still further east, and so approaching the Abu mass of Erinpura granite, mica-schists crop out. Phyllitic rocks form the hills south-east of Palri, their general strike being N. E.–S. W.

Shales and mica-schists.

Dodia-Malgam Tract.

The Aravallis constituting this tract bear many resemblances to those found in the Sindret-Undwaria region, but the lower members seem to be missing. A glance at the map (Plate 12) will show the peculiar configuration of this tract in its northern part near Dodia, where it is 'cut off' by Erinpura granite. Its width here is only about two miles; but in spite of this, shales and shaly types predominate. Intrusive pegmatite of the Erinpura granite is not common, but there are numerous Malani intrusives, most of which cut slightly across the approximately N. E.–S. W. strike of the shales.

Lowest members missing.

In the stream bed between Balda and Bilangri (sheet 95), numerous local changes of dip and strike may be observed, in certain places the strike being almost E.–W.; but the general dip is 70°–80° to the north-west. Spotted mica-schists occur (42/309, 21225).

Descriptive notes.

Exposures are poor in the Bilangri grass reserve, but south of this, abundant amphibolites intrude the rocks, which here are mica-schists or quartz-mica-schists (42/221, 21123; 21064). Injection types of schist and gneiss occur a few miles north of Pamera (sheet 96). These types are more plentiful in the Anadra-Mandar area

where they are described fully (*see* pp. 26-27). Quartz-mica-schitfs (42/172, 21059) occur just south of Pamera. These frequently contain felspar from the pegmatite.

A thin calcareous band (42/176, 21067) crops out 1½ miles north-west of Poitra (sheet 96). The metamorphism of this has produced a rock composed chiefly of calc-silicates.

Dantrai-Kankodara Remnants.

The Dantrai-Kankodara remnants or roof-pendants consist of a series of inliers of Aravalli rocks in the Erinpura granite. The general facies of these rocks is more arenaceous than in the two more easterly tracts just described. Thus in the big mass near Kankodara, a well-developed quartzite (42/239, 21143), containing a fair amount of muscovite, forms the ridge running between Poidara and Kankodara (sheet 95) and also forms the hill one mile north-east of the latter village. The neighbouring hills are composed of thin quartzitic shales and phyllitic schists, with amphibolites, abundant pegmatite and fine-grained aplitic Erinpura granite. The quartzites in the south have a more or less general N. N. W. dip of about 60°-75°.

Isolated inliers of Aravallis of arenaceous facies.

Descriptive notes.

The inlier south of Taunri (sheet 95) is composed of injection types of schists with pegmatite, abundant dolerites and amphibolites.

The mass north-west of Sanpura (sheet 95) is the largest of these remnants. As in the case of the other inliers of Aravallis, its junction with the Erinpura granite is very irregular; also numerous intrusions of the granite, with its pegmatite, are found in the mica-schists which form the bulk of the rocks. The presence of these intrusions sometimes assists the schists to resist atmospheric weathering to a greater degree, with the resultant formation of quite imposing peaks standing above the general level of the neighbouring rocks. An example is given by the large hill half-way between Amlari and Sanpura. Biotite-quartz-schists (21121) were noted half a mile north of Sanpura.

The several isolated inliers of Aravallis south of Amlari (sheet 95) possess a very strong arenaceous facies and, as a rule, are profusely intruded by dolerites. Two sections (21098; 21099) of rocks from the hills three miles N. N. E. of Dantrai (sheet 96), show fine-grained chlorite-sericite-quartz-schists with a little biotite.

The most southerly members of this series of remnants occur near Dantrai. A section of the rock (42/195, 21090) forming the hill at this village shows it to be similar to the last described rocks but with more biotite, finer-grained in texture. Quartz-tourmaline-pegmatite (21091) was found intruding this rock.

Motagaun-Haliwara Remnants.

Descriptive notes.

A large inlier of Aravallis west of Motagaun (sheet 95), the western boundary of which approximately follows the Sirohi-Jodhpur frontier, is composed of micaceous quartz-schists (42/250, 21156; 42/251, 21157), thin quartzites and shaly quartzites, all intruded by abundant pegmatite and amphibolites, as well as by dolerites. The quartzites are occasionally massive, but not to any considerable extent. The general strike of the rocks is N. E.–S. W. but it varies locally. The usual dip is to the north-west.

An interesting black quartzite (42/258, 21164) caps the top of the hill 1¾ miles N. N. W. of Motagaun. It is intruded by veins of Erinpura granite and its pegmatite.

Apart from an isolated exposure of quartzitic rocks N. N. W. of Phungni, the next inliers of Aravallis found along the strike of the Motagaun rocks occur near Haliwara (sheet 95). These are mostly quartz-mica-schists, and on account of the poorness of the exposures, their exact boundaries are uncertain.

Anadra-Mandar Area.

Large spread of Aravallis.

The Aravallis form a large spread between the southern part of the Abu *massif* and the Erinpura granite cropping out between Magriwala (sheet 76) and Reodhar (sheet 96) and to the south. South-west of Magriwala, towards Mandar, isolated outcrops of schists and limestone appear through the alluvium.

Schists and injection types common.

The commonest rocks in this area are mica-schists (biotite and muscovite-), but very frequently the abundance of thin veins of injected pegmatite derived from the Erinpura granite is such that the rock is best termed an injection gneiss. An example of this type (36/801, 17608), from one mile north of Amlia (sheet 77), shows garnets with abundant quartz, biotite, chlorite and muscovite, and

with a little iron-ore. Garnets, however, are not always present in the injection types and garnetiferous mica-schists in these Aravallis are the exception rather than the rule.

Localities of injection types.

These injection types of rock occur in the neighbourhood of the following villages in the area under consideration:—

Sheet 96.—Dadera, Reodhar, Basan, Nimbora, Dholpura, Dhauli, Makawal, Hemro, Gagrotio, Salotra, Bhatana, Gorli.
Sheet 97.—Padar, Kapasia, Dibri, Amodra.
Sheet 76.—Jabto, Kotra, Fatehpur, Piloti.
Sheet 77.—Amlia.

They are thus commonest in the extreme south-west of the State where the metamorphism appears to have been the most severe. The general schistosity of these rocks corresponds to the N. E.-S. W. strike of the less metamorphosed Aravallis in the other parts of the State. They frequently possess, however, if one might be permitted to use the term, 'rolling dip', with consequent changes of 'strike'. Other rocks occur associated with them as, *e.g.*, near Makawal, where thin quartzite bands and occasional limestones are found. Highly metamorphosed basic rocks, presumably intrusive, are very common; these will be discussed later (*see* p. 53). Quartz-pegmatite veins cut the Aravallis; and in the south-western extremity of the State, a series of post-Malani basic dykes strike E.-W. (*see* pp. 142-145).

Chlorite-schists.

Chlorite-schists occur, but they are not as common biotite-schists. A good exposure occurs at Sanar (sheet 97), stretching into Palanpur.

Crystalline limestones.

The limestones and calcic types found associated with the mica-schists of this region, are generally thin and discontinuous[1] though, with their rolling dips, they at times have a fair extent of outcrop. The following brief account gives details of their field relationships but reference must be made to the economic section of this memoir (Chapter XIII) for analyses of picked examples and the question of their utilisation, past and future.

The term limestone is used in a general sense in connection with these Aravalli calc-rocks. Most specimens are in reality crystalline

[1] F. J. North, 'Limestones, their Origins, Distribution and Uses', London, pp. 61-64, 1930).

limestones, certain examples being fine white saccharoidal marbler. Descriptions will be given of the various types found, including the impurer varieties constituting calc-schists and calc-gneisses. These latter are the metamorphic derivatives of impure argillaceous limestones.

The band of limestone south-east of Dungrari has a general dip of 80° to the north-east. This variation of strike and dip is local.

Dungrari limestone.

Numerous small outcrops of calcareous rocks occur among the schists between the Dungrari exposure and the Selwara hills. They are generally very impure and discontinuous in extent.

In the hills W. S. W. of Selwara, which culminate in the peak of 1,356 feet elevation, a bed of crystalline limestone lies apparently conformably upon mica-schists, the general structure as seen from a distance to the south-west appearing as shown in the accompanying sketch section (Fig. 2).

Selwara crystalline limestone.

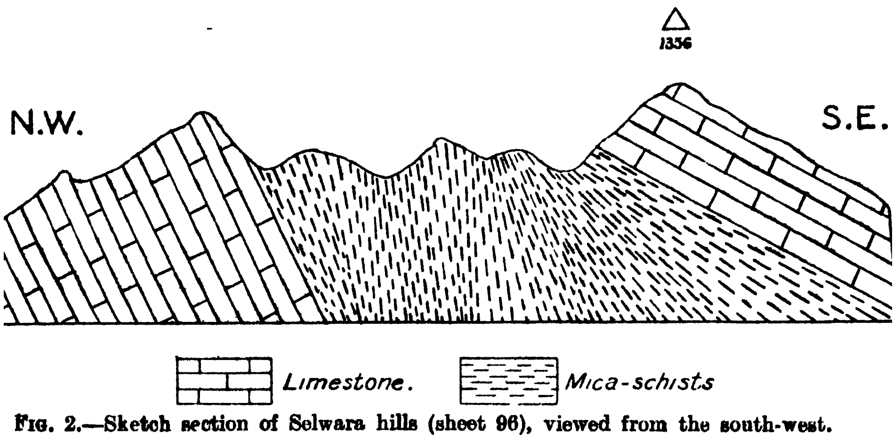

FIG. 2.—Sketch section of Selwara hills (sheet 96), viewed from the south-west.

The dip of the limestone varies greatly and the limestone appearing on either side in the above figure, coalesces to the north-east to form a single mass, the general shape of the outcrop in plan being somewhat similar to an arrow-head, pointing to the north-east. The foliation of the schists is rather obscure, but in general follows that of the overlying limestone, tending, however, to verticality in the centre.

A specimen from one mile E. S. E. of Warka (42/180, 21071) shows a crystalline limestone containing quartz and diopside. An-

other from 1¼ miles W. S. W. of Selwara (36/812, 17622) contains a fair amount of tremolite.

Perwa and Serwa crystalline limestones.

The crystalline limestone cropping out in the vicinity of the villages of Serwa and Perwa has considerable economic importance and is discussed in that section (*see* p. 159). On the southern side of these exposures, there are large intrusions of epidiorite (17620; *see* p. 53). A specimen of the rock quarried half a mile W. N. W. of Perwa (36/768, 17619) proves to be a white, saccharoidal marble containing diopside. Calculation from the analysis of this specimen given on page 157 also indicates the presence of free quartz in the rock, though this was not observed in the section. The dips and jointing of the marble are confusing.

Raonakwara limestone.

The limestone near Raonakwara has rolling dips; this outcrop is so intruded by pegmatite that its economic value is poor. The same remarks are applicable to the limestone outcrops in the extreme south-western corner of sheet 96 in the vicinity of Dewari. The rock is of no great thickness, has rolling dips, and is intruded by pegmatite and amphibolitic rocks; it is generally well crystallised. The calcic rocks are very variable in nature near Khan (sheet 96); within the space of a few feet, they alter from a marble (42/186, 21077) to a calcite-diopside-rock (42/187, 21078) and to a diopside-epidote-rock (42/188, 21079).

Piloti marble and Kotra calciphyres.

Purer varieties of marble are found in the south-eastern corner of sheet 76. The analysis of a specimen from Piloti (36/770), given on page 157, shows an insoluble residue of 3·96 per cent. and 3·47 per cent. of magnesia. In the larger exposure of calcic rocks west of Kotra, however, calciphyres occur. In one specimen (36/803, 17610), abundant calcite, with diopside, zoisite, quartz and scapolite occur; the last mineral can be seen to be derived from felspar. A section of a different specimen (17612) contains in addition tremolite, clinozoisite, phlogopitic mica and microcline. Apatite and more phlogopite were noted in a third specimen (36/804, 17611). The pleochroism of the phlogopite is :—

$\mathfrak{a}$ = light yellow-brown,

$\mathfrak{b}$ = dark brown,

$\mathfrak{c}$ = yellowish dark brown.

Absorption :— $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

Sirohi-Erinpura Tract.

The rocks found in the Sirohi-Erinpura tract are in many ways similar to those in the other subdivisions. In the north, near Dharmano (sheet 117), the predominant types are mica-schists and arenaceous rocks with occasional bands of limestone, all being largely intruded by tourmaline-pegmatite and occasional dolerites. The limestone and quartzite assist the schists to form relatively high and rugged hills compared with those formed by the softer Erinpura granite. Limestone predominates in the hills south-east of Khandra (sheet 117), but there are also arenaceous and argillaceous types. Calcic types crop out in force in the range of hills running between Utan (sheet 117) and Palri (sheet 94), but hornfels and altered slaty quartzites occur. It is impossible to map the boundaries between the various rocks found here, the confusion being increased by numerous intrusions of pegmatite.

Mica-schists predominant.

Limestone occurrences.

There is an outcrop of limestone at Mandwa (sheet 95), much intruded by quartz-pegmatite, but which in places is sufficiently pure to be burned for lime. Erinpura granite borders this to the south and east. The low hills to the south-west of Mandwa are composed of limestone, intruded by quartz-pegmatite and amphibolitic rocks.

A white quartzite, comparable to the Kankodara specimens described before, forms the major part of the hills north-east of Morli (sheet 94), whilst the hills immediately east and south of that village are composed of highly altered schists and argillaceous types. A similar quartzite forms the range 1¼ miles east of Palri and the station 938 feet in the north-east corner of sheet 95.

Quartzite.

The rocks found at the junction of the four sheets 94, 95, 117 and 118, are extremely interesting. Hill station 1,956 feet is composed of hardened slates, quartzites and mica-schists. To its south there is an abundance of amphibolitic rocks of composite nature which have been discussed later (*see* pp. 49-53). Between these and Utman ki Bhagli (sheet 118) are two elongated inliers of Aravallis, composed chiefly of mica-schists with bands of limestone and with many intrusions of Erinpura granite.

Composite amphibolitic rocks.

There is a large spread of Aravallis a few miles north-east of Sirohi. These are composed chiefly of mica-schists, but quartz-schists, green quartzites, quartz-mica-schists, phyllites, hornfels, etc., are found. The quartzitic types form the higher hills. The general strike of these rocks varies from N. E.–S. W. to N. N. E.–S. S. W., with dips to the south-east or E. S. E. of 70° to 90°. At the foot of hill station 2,205 feet is a much altered, thin limestone band which is burnt for lime. Basic rocks do not occur in force, but there are frequent intrusions of pegmatite which, near Balda (sheet 95), have formed greisen (*see* p. 72). Garnetiferous mica-schists occur in the neighbourhood of this village. The mica-schists frequently contain concretionary masses (17045; 17046) which are composed of fine sericitic mica, biotite and quartz, with occasional small garnets.

Rocks near Sirohi.

The rocks in the road at the south-east corner of Sirohi town comprise quartzites, micaceous quartzites, phyllitic types and zoisite-sericite-schists (17021). The thin band of Aravalli mica-schists stretching S. S. W. from Sirohi is almost obliterated by amphibolites and epidiorites, with abundant quartz-pegmatite intrusions.

Garnetiferous mica-schists.

Garnetiferous mica-schists crop out south of Telpur (sheet 95) and are accompanied by some injection types.

Correlation.

Whilst the evidence for placing the rocks of the other subdivisions in the Aravalli system is considered conclusive, the position of these rocks of the Sirohi-Erinpura tract is more open to question. Their general resemblance is with the Aravallis rather than with the Delhis described hereafter; also, by correlation with the other exposures of Aravallis in Jodhpur to the north, it is more reasonable to consider those rocks west of the Abu-Erinpura range as Aravallis.

CHAPTER IV.

DELHI SYSTEM.

Stratigraphical Subdivisions—Ajabgarh Series.

Position and extent.

Rocks correlated with the Delhi system crop out in Sirohi State south-east of an imaginary line joining Erinpura Road railway station (sheet 117) with Vasra (sheet 97). Numerous intrusive rocks, however, are found covering a large part of the surface in this region.

Ajabgarh series.

In his comprehensive memoir on the geology of North-Eastern Rajputana, Dr. A. M. Heron gives a list[1] of the various series constituting the Delhi system, but all of the constituent series are not represented in Sirohi. The Raialo limestone and quartzite, which Dr. Heron now regards as being sufficiently important and being separated from the higher members of the Delhis by such an unconformity to warrant the Raialos being regarded as a separate system,[2] have no representatives.

Quartzites certainly occur, but they do not resemble the massive quartzites of the Alwar series, though the doubtful possibility of their belonging to the Alwar series is admitted. Again limestones are found, but they have no resemblance to the Kushalgarh limestone. The Delhi representatives in Sirohi have been correlated with the highest members of that system, *viz.*, the Ajabgarh series.

General facies.

Dr. Heron has noted that the Ajabgarh series

'is a formation in which argillaceous rocks predominate, with subordinate impure quartzites and limestones'.[3]

He adds that the

'facies shows deeper water deposition than the Alwars, and at certain horizons rapid but not great variations in the conditions, but neither the shallow water characters of the lower Alwars nor beds usually taken as indicating deep water sedimentation are seen'.

There appears to have been a progressive deepening of the Ajabgarh sea in Sirohi, limestones forming the uppermost members. The

[1] *Mem. Geol. Surv. Ind.*, XLV, p. 10, (1917).
[2] *Rec. Geol. Surv. Ind.*, LXII, pp. 172-173, (1930).
[3] *Mem. Geol. Surv. Ind.*, XLV, p. 14, (1917).

series as exemplified here possesses a facies more calcareous than the parts of Rajputana described by Dr. Heron in the memoir cited, but comparable with the Udaipur occurrences, the description of which will shortly be published.

Strike.

The general strike of the northern outcrops of the Delhis corresponds to the usual N. E.–S. W. to N. N. E.–S. S. W. strike of the Aravallis. Dips flatten and the strike changes as one proceeds south-west. The general structure has been discussed in Chapter XIV.

Subdivisions of the Ajabgarhs.

In the map attached to this memoir, it will be noted that the Ajabgarhs have been subdivided as below, the youngest beds uppermost:—

3. Calc-gneisses, calciphyres and limestones, with amphibolitic rocks.
2. Mica-schists, phyllites, etc., with amphibolitic rocks.
1. Quartzites.

Detailed notes will be given regarding each of these subdivisions.

Quartzites.

Uniformity of outcrop.

The oldest members of the Ajabgarhs are composed chiefly of quartzites, which usually form high hills owing to the more resistant nature of these rocks compared with the schists and limestones. They appear on the map as a number of disconnected, elongated outcrops, usually surrounded on all sides by the younger mica-schists. All the Ajabgarh quartzites occur not very far removed from an imaginary line joining Kalumbri (sheet 118) in the north-east with Sur Paga (sheet 97) in the south-west. There seems to be no doubt from their distribution and appearance that these quartzites represent the metamorphosed equivalents of the same original sandstone bed.

Ramserji quartzite.

Examining the outcrops from north-east to south-west, the first exposure is met near Kalumbri, where a quartzite forms a thin ridge, trending first due south, and then more south-westerly. Hand specimens and sections of this quartzite (34/230, 16187; 34/239, 16202) show it to be almost entirely composed of quartz with a little tourmaline and mica. North of Ramserji, towards Dhanga (sheet 118), there are two or more ridges of quartzite apparently interbedded with the mica-schists; these quartzites have a strong dip of some 50° E. The

country south of Ramserji is exceedingly rough and the boundaries of the quartzites are more or less conjectural. The isolated hill station of 2,053 feet, to the west of Ramserji, is composed of a quartzite whiter in colour than the Ramserji example.

Jaba quartzite.

The quartzite forming Jaba Hill, north-east of Wasa (sheet 119), stretches for some four miles, the strike changing from N. E.–S. W. in the north, to E.–W. in the centre, and back to the original strike in the south. From a distance it appears almost as if the hill were capped by quartzite; but when one approaches close to it, it is obvious that the quartzite has an almost vertical dip, with a slight inclination to the south-east. The quartzite ends abruptly at either end against schists. It is introduced in places by quartz-pegmatite.

Watera quartzites.

There are about seven isolated hills of quartzite near Watera (sheet 96). The rock here, as at Sanwara, grades into a rock resembling quartz-reefs. All the exposures end abruptly against either mica-schists, amphibolites or limestones and appear to be the disjointed remnants of a hard quartzite which has not responded well to the folding movements just before the intrusion of the Erinpura granite. The rock itself (34/257, 16227) is very fine-grained with small flakes of biotite and sericite in parallel alignment.

Deldar quartzite.

A large spread of quartzite, a mile or so wide, commences three miles S. S. E. of Watera and trends south-westerly for ten miles, ending with isolated outcrops east of Sagna (sheet 97). This quartzite was mapped by Hacket, but the boundaries have been altered and its extent reduced. It forms high hills, many of which, *e.g.*, hill station 2,557 feet, are difficult of ascent. Its field relations and petrological characters (36/771, 17575) are similar to the Jaba quartzite. The irregular nature of its junction with the surrounding amphibolitic and phyllitic rocks is well seen between Tankia and the hill station 2,812 feet (sheet 96). A view of this latter hill from the limestone hills on the east side of Tankia, is very reminiscent of Jaba Hill with its precipitous sides and abundant screes.

Bandia Gadh quartzite.

The quartzite forming the southern part of the ridge containing hill station 2,842 feet, east of Bandia Gadh (sheet 97), is of interest as it appears to be faulted against the limestone to the north and east. The relations are shown in the section across this area (Plate 11, fig. 1).

The Mandwara and Chandrawati brecciated quartzites described hereafter do not wholly belong to the Ajabgarh quartzites, though parts of the former do. Their siliceous character is considered to be due largely to solutions, concentrated as an acidic differentiation product of the Erinpura granite, which gave rise to the quartz-pegmatites described later (*see* pp. 69-71).

Brecciated quartzites.

The quartzite running through the villages of Mandwara and Sanwara (sheet 119) resembles the Jaba quartzite in its north-easterly part; but it grades into a more brecciated type. It is very ferruginous near Mandwara, but it loses this nature to the south-west. Hand specimens and sections (34/256, 16222; 16225) show that it is a brecciated rock; quartz, the main constituent, shows strain polarisation colours; the other minerals present are biotite, sericite, a little microcline and iron-ore, which, as stated above, is most common near Mandwara. Part at least of the silica in this rock is derived from solutions.

Mandwara brecciated quartzite.

There is a small range of hills between the limestone and plains, south-west of Chandrawati (sheet 97), which is composed chiefly of a brecciated quartzite (36/786, 17593) similar to parts of the Mandwara quartzite. In places this is very limonitic; generally it contains abundant quartz with occasional large felspars. It is a fault-rock, the siliceous character being largely due to solution agencies. As one follows it to the north, its brecciated character persists (36/793, 17602), but towards Sathpur, the rock is best termed a brecciated limestone. Reference will be made to this rock when the structure of the area is considered (*see* p. 164).

Chandrawati brecciated quartzite.

Mica-schists, Phyllites, etc.

Rocks belonging to the intermediate subdivision, termed 'mica-schists, phyllites, etc.', cover the largest area of any of the three subdivisions. The predominant rocks are mica-schists, but associated intimately with these are numerous amphibolitic rocks, the age and nature of which is rather obscure. Most of them possess the same foliation planes as the schists and so they are certainly older than the Erinpura granite, by which and by the pegmatite of which they are profusely intruded.

Largest division of Ajabgarhs.

In general, however, it is not thought that they are contemporaneous with the schists as was considered to be the case for the basalts and tuffs associated with the lowest members of the Aravallis. It is considered that they represent later, but pre-Erinpura-granite, intrusives injected chiefly as sills into their associated Ajabgarh rocks (*see* pp. 45-49).

Associated basic rocks.

These basic rocks are most commonly found associated with mica-schists, but they also occur with the calcic rocks of the next subdivision to a lesser extent. In this connection, the following passage from Dr. Heron's memoir in connection with the amphibolites associated with the Alwars is of interest:—[1]

'It is found that bands of mica-schists and conglomerates with a micaceous matrix are favoured, in comparison with quartzites, as an avenue of injection, from obvious mechanical reasons, while in limestones it would appear (I suggest this with all caution) that the thinner trap sills and veins are to some extent absorbed, with mutual chemical reactions resulting in the formation of actinolite, tremolite and epidote.'

It will also be seen that the metamorphism and injection of these amphibolitic rocks has given rise to a suite of rocks of distinctive characters. Accordingly it is proposed to postpone the discussion of these amphibolitic rocks and their products, in so far as it is possible, to the next chapter where they will be discussed in full detail. The possibility, however, of certain of the amphibolitic rocks being derived from the metamorphism of sediments and limestones has not been overlooked. Chemical criteria as noted by Bastin[2] and criticised by Trueman,[3] Leith and Mead,[4] and Stillwell[5] cannot be applied as no analyses are available.

The largest spread of mica-schists runs approximately southwest from Keshavganj (sheet 118) to Abu Road (sheet 97) on either side of the railway line. A good part of the surface of this area is covered with alluvium, but exposures in the river beds and the general character of the soil enables one to mark their boundaries with fair accuracy, except, of course, those with the

Keshavganj-Abu Road area.

[1] *Mem. Geol. Surv. Ind.*, XLV, pp. 90-91, (1917).

[2] E. S. Bastin, *Journ. Geol.*, XVII, pp. 445-472, (1909); *op., cit.*, XXI, pp. 193-201, (1913).

[3] J. D. Trueman, *op. cit.*, XX, pp. 229-258, 300-315, (1912).

[4] C. K. Leith and W. J. Mead, 'Metamorphic Geology', New York, pp. 226-242, (1915).

[5] F. L. Stillwell, 'The Metamorphic Rocks of Adelie Land, Section I', Sci. Rept. Austn. Antarct. Exp., Series A, III, Pt. 1, pp. 118-121, (1918).

accompanying basic rocks. They are profusely intruded by quartz-pegmatite veins and, near Kacholi, by a large mass of Erinpura granite. Quartz-chlorite-schists (34/259, 16229) and quartz-actinolite-schists (34/259, 16228) occur east of this in force. It is in this region, two miles north-west of Rohera, that one finds old pits, said to be dug for the extraction of gold (*see* p. 155).

This area is separated from two elongated outcrops of schists by exposures of limestones belonging to the highest subdivision of the Ajabgarhs. The northern outcrop is found on either side of the Ramserji quartzite; and then, south of Watera (sheet 96), lies to the east of the Deldar quartzite, its part west of this quartzite being greatly compressed. Hard quartz-tremolite-schists (16193) are found one mile north-west of Wasa (sheet 119). In the vicinity of Gadh (sheet 97), east of the Deldar quartzite, the strike or schistosity varies greatly, giving in consequence a wide spread of phyllites, with abundant amphibolitic rocks and subordinate schists. A specimen of tremolite-quartz-schist (17600) was noted two miles south-east of Sagna.

Ramserji-Gadh area.

The southern elongated outcrop stretches from south-west of Watera (sheet 96) to Chanda ji ka Gara (sheet 97) on the frontier with Danta State. These schists, as usual, contain abundant amphibolitic rocks and, also, occasional thin bands of limestone. Injection types, very similar to Aravalli occurrences previously described (pp. 26-27), are in force from east of Abu Road station to the border with Palanpur and with Danta. Taking the presence of these types as evidence of very severe metamorphism, it would appear that as is the case for the Aravalli rocks, west of the Abu *massif*, the metamorphism of this tract appears to increase in severity as the rocks are traced along their strike from the north-east to the south-west. This, however, as will be seen, is not the case for all the Ajabgarh rocks.

Watera-Chanda ji ka Gara area.

Highly metamorphosed rocks form a narrow band on the Sirohi-Udaipur frontier east of Pindwara (sheet 118). Erinpura granite forms the summit of this bordering range; but biotite-schists (34/225) and quartz-mica-schists (34/226; 16190) form the low ground, with amphibolitic types (34/227, 16182; 34/228, 16185) forming the flanks. Certain of the schistose rocks (16181) contain abundant felspar, derived undoubtedly from the Erinpura granite or its pegmat-

Sirohi-Udaipur frontier region.

ite. The distinction between injection-gneisses and gneissose Erinpura granite is a matter of considerable difficulty, especially in the neighbourhood of Moras (sheet 119).

Quartz-mica-schists (34/242, 16205), frequently garnetiferous (34/243, 16206) and approaching injection-gneisses (34/244, 16207), crop out on both sides of the river valley forming the Moras pass into Udaipur. This river flows through Erinpura granite further west, but along the extended village of Waloria, its course is again through amphibolitic rocks and schists which are occasionally garnetiferous and also contain tourmaline (34/238, 16201).

Schists, with associated amphibolites, again occur in force between the Waloria and Bhula masses of Erinpura granite (sheet 119). The hills named Babera and Hindola on the one-inch sheets are composed of these rocks and the influence of the adjoining granite is shown by the formation of tourmaline-quartz-biotite-schists (34/236, 16197). A chlorite-actinolite-schist (34/252, 16217) from north-west of Nawawas (sheet 119) contains abundant chlorite and actinolitic hornblende. The indices of refraction of the chlorite, measured in sodium light, are as below :—

$$\alpha_{Na} = 1{\cdot}586 \pm 0{\cdot}001$$
$$\beta_{Na} = 1{\cdot}586 \pm 0{\cdot}001$$
$$\gamma_{Na} = 1{\cdot}590 \pm 0{\cdot}001$$
$$= 0{\cdot}004$$

Those of the actinolitic hornblende are :—

$$\alpha = 1{\cdot}620 \pm 0{\cdot}002$$
$$\beta = 1{\cdot}633 \pm 0{\cdot}002$$
$$\gamma = 1{\cdot}642 \pm 0{\cdot}002$$
$$\gamma - \alpha = 0{\cdot}022$$

Abundant injection-gneisses occur in this area, especially in the neighbourhood of Bori ki Bhuj. Hand specimens and sections of these (34/253, 16219; 34/254, 16220) show the presence of abundant quartz and biotite, with lesser amounts of muscovite, felspar and garnet. In hand specimens, the pegmatite appears as discontinuous stringers, the white 'splotches' of felspar showing up against the darker coloured schistose part of the rock. A weathered surface shows the true nature of the specimen better than a fresh surface,

The boundaries of the cigar-shaped outcrop of Erinpura granite in this region are only approximate; numerous intrusions of granite occur and it is impossible to map their boundaries on maps of the scale of one inch to the mile.

Deri area.

In the Deri region (sheet 97), adjacent to Danta State and south of the horseshoe-shaped Gorsa mass of Erinpura granite, the metamorphism is again intense but the rocks are chiefly of a more arenaceous facies (36/781, 17586; 36/782, 17587; 36/784, 17589) than in the Bori ki Bhuj region; certain of these rocks are friable in the hand specimen. Mica-schists also occur, at times associated with numerous amphibolitic rocks and profusely intruded by pegmatite.

Prevalence of injected types.

The prevalence of injected types of a highly metamorphosed nature throughout the whole of the frontier region with Udaipur will have been noted. The severe metamorphism is not to be wondered at when it is remembered that the bordering hills are really the fringe of the old 'Aravalli' mountain range, using the term 'Aravalli' in its physiographic sense. These Delhi schists are, as a whole, far more metamorphosed than the older Aravalli rocks to the west of Abu, though the Aravallis in the southern part of the Anadra-Mandar area show similar injected types.

Phyllitic types.

It is only exceptionally, however, that one gets phyllitic types in the Sirohi Ajabgarhs. Strangely enough, these occur further to the south:—in the area near Gadh already mentioned (*see* p. 37) and in the inlier of rocks, surrounded by limestones, which occurs north-west of Bhamoria (sheet 97). Here phyllitic types are abundantly intruded by quartz-pegmatite and amphibolitic rocks. Their general occurrence is of a broad anticline with the phyllites dipping under the calcic rocks. Many local inversions, though, have been noticed.

Calc-gneisses, Calciphyres and Limestones.

Importance of the calcic rocks.

The calcic rocks forming the uppermost division of the Ajabgarhs are in many ways the most interesting rocks in this series, not only on account of their economic importance, but also owing to the variety of types present. These rocks also give invaluable aid in the elucidation of the structure of the area.

The largest spread of calcic rocks is found in the south-eastern corner of the State; here they extend into Danta State to the south and into Idar to the east; they crop out as far as Bhula (sheet 119) to the north. After some isolated outcrops, another great exposure of these rocks is found to the east of Pindwara; this extends to Jodhpur State to the north-east and can be traced south-west through Sirohi almost to Palanpur State, a distance of some 40 miles. Though the major part of these calcic rocks lies to the east of the railway line, there is an area of them north of Abu Road and a thin band more or less follows the eastern boundary of the Abu-Erinpura mass of Erinpura granite.

Distribution.

The country forming the south-eastern corner of the State is very rough. There are but few tracks which allow camel transport to be used and generally bullock-cart transport is out of the question. Such tracks that there are usually follow the courses of the rivers which, in the limestone country, abound with small waterfalls.

South-eastern corner of the State.

The general structure is that of a synclinorium (*see* Plate 11, figs. 1 and 2), but the calcic rocks show innumerable variations of dip and strike; rolling dips predominate but in many places the dips are vertical. The contortion and inversion of dips in this corner may be confidently ascribed to the intrusion of the Gorsa mass of Erinpura granite (*see* pp. 65-66). Numerous amphibolitic rocks are associated with the calcic types; many of these amphibolites were intruded as sills before the Erinpura granite and consequently have been folded with the calcic rocks (*see* p. 49). Innumerable varieties of calcic rocks are found; the chief of these will now be described. It is worth noting in passing that in Sirohi, calcic rocks have been mapped as one stage of the Ajabgarh series. In the contiguous areas to the east, Dr. A. M. Heron and Mr. J. B. Auden have mapped two divisions of calcic rocks, 'calc-schists' being the older, and being followed by 'calc-gneisess and calciphyres, biotitic limestones'. Division into two such stages was not found possible in Sirohi, owing to the greater amount of intrusives.

Structure.

In the valley and hills east of Jaidro (sheet 97), the general dip is 10°-20° E. S. E. to south-east The calcic rocks contain abundant calcite, quartz, tremolite and diopside with subordinate plagioclase. They are thus calc-

Jaidro.

gneisses (36/772, 17576; 36/773, 17577). The proportion of diopside and tremolite is variable to a remarkable degree within a very short distance. The rocks are intruded to a fair extent by quartz-pegmatite. Mica is very common in the calcic rocks stretching from Jaidro to Bori ki Bhuj and Bhula. In a specimen (16218) from north of Bori ki Bhuj, diopside and zoisite, with characteristic colours, are common, with subordinate quartz and felspar. In certain cases, the shapes of aggregates of zoisite and quartz suggest they may be alteration products of garnet.[1]

Khejra. The calcic rocks are again very tremolitic along the Khejra valley (sheet 97), their dip being generally E. S. E.

The hills between the stations 2,773 and 2,842 feet, south-west of Uparla Gadh (sheet 97), are composed of calcic rocks with

Uparla Gadh. abundant diopside; one specimen of diopside-rock (36/777) has a density of 3·13 and consists almost entirely of diopside. The refractive indices of the diopside lie between 1·680 and 1·705. Amphibolitic rocks are common in this area and the metamorphism of the calcic rocks has given interesting products. The amphibolitic nature is predominant in some cases. One such example (17581) contains abundant quartz, microcline, plagioclase and hornblende, with little or no calcite. A little poikilitic tourmaline occurs in the rock; it is strongly pleochroic :-

ω = deep bluish violet,

ε = pale greenish pink.

Absorption :— $\omega > \varepsilon$

It is probably a *tourmaline ferrifère*.[2] This slide also contains a cleaved dirty-looking mineral, birefringence=?0·019, positive elongation, negative optical character, small optic axial angle, which is probably an alteration product of scapolite. These diopsidic and amphibolitic rocks weather very similarly to limestones.

The rocks are extremely contorted in the river valley between Raro and Bore (sheet 97), due no doubt to the intrusion of the Gorsa mass of Erinpura granite mentioned above (*see* p. 40; also, pp. 65-66). This contortion is well displayed by bands of limestone which are hopelessly intermixed with amphibolitic and schistose

[1] C. R. Van Hise, *Mon. U. S. Geol. Surv.*, XLVII, p. 303, (1904).

[2] A. Lacroix. 'Mineralogie de Madagascar', I, pp. 411-412. (1922). *See* also A. Lacroix, 'Mineralogie de la France et de ses colonies', I, p. 81, (1893).

rocks. The general strike, however, is N.–S., parallel to the boundary of the granite.

Jamburi.

South-east of Jamburi (sheet 97), calcic rocks adjoin the Erinpura granite in Idar State ; they are greatly intruded by amphibolites and pegmatite, but in certain cases, as at Bosa, they are moderately pure. A specimen (36/778, 17582) shows a fair amount of quartz and diopside ; certain of the calcite crystals show curved lamellae. The crystalline limestones contain abundant amphibolitic rocks between Taleti and Bosa, but those north-east of hill station 2,301 feet are relatively pure.

Deri and Ghoratankri.

The bow-shaped or horseshoe-shaped outcrop of the Deri and Ghoratankri area, enclosed by the Gorsa mass of Erinpura granite, is interesting from an economic standpoint, especially the outcrops near the latter village. These have been discussed in detail in the economic section of this memoir (*see* p. 158). The Ghoratankri rock (36/769, 17583 ; 36/779, 17584) varies from a recrystallised impure limestone to a white saccharoidal marble. An analysis of 36/769, the former type, is given on page 157 where it will be seen that there is 16·16 per cent. of insoluble residue. Specimen 36/779 is probably much purer than this.

North-eastern corner of State.

The second great expanse of calcic rocks has been described as extending from Pindwara (sheet 118) to Palanpur State (sheet 97). This divides near Sabela (sheet 118) into two S. S. W.-stretching bands. The more westerly of these continues past Abu Road (sheet 97) as described above. The easterly band dies out near Waloria (sheet 119). The calcic rocks vary in hardness, being at times hard, compact and fine-grained as in the ranges of hills near Garh (sheet 119), north of Nawawas, and south-west of Watera. Hand specimens and sections of these (34/224, 16180 ; 34/229, 16186 ; 34/232, 16191 ; 34/258 ; 34/251, 16216 ; 36/158, 17136) show recrystallised micaceous limestones, containing abundant calcite with varying amounts of a phlogopitic mica, iron-ore and quartz. The mica has been termed phologopite as its characters under the microscope (16186 ; 17136) most resemble that mica. The general colour of hand specimens is grey, but varies with the purity of the rock. A hand specimen (34/224) from Kundal (sheet 118) is almost black.

Four of the above specimens (34/232, 34/251, 34/258 and 36/158) have been analysed with the results given on page 157. It will be noted that the respective percentages of insoluble residue are 12·24, 10·64, 3·02 and 6·70.

Apart from these harder types, softer varieties of calcic rocks are met, chiefly in the north-eastern corner of the state in the vicinity of Sabela (sheet 118). Sections of these (16177, 16178, 16179, 16183 and 16199) show abundant calcite with more phlogopitic mica than in the harder types, and also quartz, iron-ore, sphene and zoisite. In 16179, there are ovoid aggregations of zoisite, calcite and quartz suggesting the possibility of the previous existence of garnets in these rocks; tremolite and a greenish brown, strongly pleochroic mineral also occur in this slide. The latter mineral is cut by a vein of calcite. Hand specimens are coarser-grained than the harder types. These rocks are profusely intruded by amphibolitic rocks and also by pegmatite.

Contact metamorphic products.

An extremely interesting series of contact metamorphic products, formed by the intrusion of an olivine-gabbro into calcic rocks, occurs in the south of the state in the vicinity of Chandrawati and Kui (sheet 97). The gabbro will be described later (*see* pp. **79-83**). Hand specimens and sections of these rocks (36/787, 17595; 36/790, 17597; 36/791, 17598; 36/795, 17601A, 17601B) prove the presence of abundant calcite, a titaniferous augite, wollastonite, prehnite, ? pectolite, felspar, quartz and diopside.

Titaniferous augite.

The titaniferous augite has been described by the author in a previous paper[1] to which reference may be made. Its chief feature of interest lies in its optical character, which varies greatly.

Wollastonite.

Wollastonite is well developed in specimen 36/787 (17595) which has a density of 2·86. Fibres of the mineral were heated with hydrochloric acid and examined from time to time under the microscope. The cold acid dissolved the associated calcite and as it was heated, gradually attacked the wollastonite. The general shapes of the fibres were unaltered but the birefringence became less and less as a skeleton of fine silica developed. Eventually a skeleton of silica remained but this bore the shape of the original fibres.[2] This bears out a

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXIII, pp. 448-450, (1930).

[2] *Cf.* C. Doelter, 'Handbuch der Mineralchemie', Dresden, II, Pt. 1, p. 449, (1914), in which it is stated that wollastonite dissolves in hydrochloric acid giving a jelly.

verbal contention of Mons. P. Gaubert to the author that when the percentage of silica is greater than about 48, the form of the body is unchanged; but when the percentage of silica is less than 48 per cent., a jelly is formed.[1]

The refractive indices for sodium light of the wollastonite occurring in 36/795 (17601A and B) are as follows:-

$$\alpha_{Na} = 1{\cdot}620 \pm 0{\cdot}001$$
$$\beta_{Na} = 1{\cdot}632 \pm 0{\cdot}001$$
$$\gamma_{Na} = 1{\cdot}634 \pm 0{\cdot}001$$
$$\gamma - \alpha = 0{\cdot}004$$

The calculation of 2 V from Bartalini's formula[2] shows a value of 44°. The mineral is negative. Actual measurement on the Federov stage of the wollastonite in section 17595, using a correction for the refractive index of the demiboule, gave a value of 2V = 38°.

? Pectolite.

What appear to be fibres of pectolite were noted in 17597 and 17598. These have positive elongation.

Prehnite.

Prehnite was recognized in the sections (17601 A and B) of the specimen from Kui (36/795); it occurs in laths associated with rhombs of calcite. Its elongation is negative; it is biaxial, positive, and its optic axial angle measured for red light by means of the Federov stage is 2 V = 65°.

Normal limestone.

A specimen of a calcic rock (36/794, 16603) from one mile south of Sathpur, between the Kui and Chandrawati gabbros, consists almost entirely of calcite with subordinate amounts of quartz, phlogopitic mica and ferruginous matter.

Bhainsasing.

The calcic rocks in the vicinity of Bhainsasing (sheet 97) are profusely intruded by doleritic rocks, some of which are undoubtedly the hypabyssal equivalents of the Kui and Chandrawati gabbros. Certain of the calcic rocks in this neighbourhood show concretions. One such concretion (17592 A and B) from one mile west of the hill station 2,158 feet was found to consist of diopside, zoisite, quartz, microcline, calcite, iron-ore and sphene.

[1] There are, as Mons. Gaubert stated, exceptions to this rule.
[2] F. Becke, 'Tschermak's Lehrbuch der Mineralogie', Vienna, p. 211, (1921).

CHAPTER V.

DELHI BASIC ROCKS.

Terminology.

Meaning of term—'Delhi basic rocks'.

The convenient description 'Delhi basic rocks' includes those basic rocks, associated with the Delhis, which are pre-Erinpura-granite in age; it also includes basic rocks, intrusive into the Aravallis, which are pre-Erinpura-granite in age.

Exact age uncertain.

From the introductory discussion given in Chapter II, and also from the description of the two upper subdivisions, or stages, of the Ajabgarh series of the Delhi system, it will have been gathered that there is considerable difficulty in giving an exact age to the amphibolitic and other basic rocks associated with the rocks of these two subdivisions. These basic rocks are very intimately associated with the schists and calcic rocks of the Ajabgarhs; they have, in fact, been subjected to the same folding movements and processes of metamorphism as these rocks.

Not strictly contemporaneous with the Ajabgarhs.

They, however, cannot all be regarded as being *contemporaneous* with the Delhis, using this word in its strictest sense as was done for the basic rocks found at the base of the Aravallis near the town of Sirohi. Thus there is no evidence, *e.g.*, of tuffs being laid down as part of the normal sequence of the Ajabgarh rocks. Intercalated sheets of basic rocks, since converted to hornblende-schists, amphibolites, etc., which are suspected of being sill-like in nature, do occur; these are younger than the rocks between which they occur and with which they have been folded. It is considered, however, that there is not much actual difference in age between these sills and the rocks into which they are intruded, while some may be contemporaneous lavas. It is possible that the earlier members of the Ajabgarhs were intruded before the whole of this series was formed and that the intrusion was of no one definite age, but continued throughout the upper part of the Ajabgarh time epoch;[1] perhaps, also, after this epoch. Reference may be made here to page 36 on which the possibility of some of the Delhi basic rocks being due to the metamorphism of sediments is admitted. The greater bulk of them, however, seems to be igneous in origin.

[1]Dr. A. M. Heron rather doubts the probability of this.

In certain parts of the State, particularly in the south on sheet 97, doleritic and epidioritic rocks, associated with gabbros, are found intruding Delhi rocks. These are much younger than the amphibolitic rocks under discussion and are treated in Chapter VII. Where, however, the metamorphism of certain of the basic rocks associated with the Delhis has been less severe than is normal, it is not possible to state to which of the basic phases, Delhi or post-Erinpura-granite, these rocks belong.

Younger doleritic and epidioritic rocks.

Mention has already been made of basic rocks associated with the Aravallis in the western part of the State. Only a few amygdaloids and tuffs associated with the lowest representatives of the Aravallis have been regarded as being strictly contemporaneous with the Aravallis. Numerous other basic rocks intrude the Aravallis and the Erinpura granite. We are not concerned here with those intruding the granite; these are generally doleritic in nature and can usually be distinguished with fair certainty from the earlier or pre-Erinpura-granite basic intrusives. The other intrusives, post-Aravalli but pre-Erinpura-granite in age, are usually altered to amphibolites or epidiorites. It may be that they were intruded into the Aravallis at the close of the Aravalli period or during the time interval that elapsed before the laying down of the Delhis on the eroded edges of the Aravallis. It may be, on the other hand, that these basic rocks belong to the same phase as the Delhi basic rocks mentioned above. This point cannot be decided, but it is convenient to consider them as the representatives of the Delhi basic rocks. However it must again be emphasised that there is no positive evidence for this correlation.

Basic rocks associated with the Aravallis.

Basic Rocks, Pre-Erinpura-Granite in Age, associated with the Ajabgarh Mica-schists, etc.

It has been considered advisable to follow the areal subdivisions of the mica-schists and phyllites adopted in the description of these rocks.

Subdivision.

The basic rocks associated with the mica-schists and other types in the large spread stretching from Keshavganj (sheet 118) nearly to Abu Road (sheet 97) are numerous and present a variety of types. In the vicinity of Kojra (sheet 119) actinolite-schists (36/73,

Keshavganj-Abu Road area: Actinolite-schists.

17048) are common. The predominant mineral is actinolite with the following scale of pleochroism :—

$\mathfrak{a}$ =yellowish green,
$\mathfrak{b}$ =dark yellow-green,
$\mathfrak{c}$ =green.

Absorption :— $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

Quartz and felspar also occur.

Tremolite-epidote-diallage-rocks (34/231, 16188) crop out near Sawarli (sheet 119); the diallage shows small twinning lamellæ parallel to (001) and also possesses a fine (100) cleavage. 'Feather' amphibolitic types (16189) were noted near the same village; these contain abundant actinolite in radiating clusters of crystals, epidote and finely granulated quartz. The pleochroism of the actinolite is :—

$\mathfrak{a}$ =pale yellowish green.
$\mathfrak{b}$ =yellow-green,
$\mathfrak{c}$ =dark green.

An actinolite-calcite-epidote-rock (16192) was noted further to the south-west, 1½ miles south of Kodarla (sheet 119); the epidote is very strongly pleochroic, pale yellow to greenish yellow. Quartz-actinolite-schists (34/259, 16228) occur in force one mile north-west of Watera (sheet 96); these also contain chlorite and a little sphene.

Watera amphibolites.

An interesting suite of amphibolitic specimens (36/162, 17140; 36/163, 17141; 36/164, 17142) was obtained two miles north-west of Watera. The mean specific gravity of the three hand specimens is 2·74. Slide 17140 shows a rock containing hornblende, quartz, felspar, apatite, chlorite, epidote and iron-ore. The pleochroism of the hornblende is :—

$\mathfrak{a}$ =yellowish green,
$\mathfrak{b}$ =dark olive-green,
$\mathfrak{c}$ =dark blue-green.

Absorption :— $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$

Slide 17141 shows a lesser amount but larger crystals of hornblende. Biotite occurs in addition to the minerals noted in 17140 and epidote is more abundant. Quartz is predominant in slide 17142 but large crystals of hornblende, with the same pleochroism as above, are not uncommon. The microscopical characters of this suite of specimens resemble those of similar rocks in the Aravallis occurring in the north-western corner of sheet 118 (*see* pp. 49-53).

Ramserji-Gadh area.

Very highly epidotised rocks (34/235, 16196) occur north-east of Wasa (sheet 119); these consist almost entirely of epidote, actinolite and quartz.

Scapolitised epidiorites occur about 2¼ miles north-east of Waloria; these (16200) contain diopside-augite, hornblende, quartz, felspar and abundant scapolite which has a low refractive index and is uniaxial and negative. Banded amphibolites (16226), fine-grained and containing ? actinolite, zoisite, epidote and quartz occur in the vicinity of Rohera (sheet 119).

Sirohi-Udaipur frontier region.

An interesting tremolite-calcite-augite-rock (16184) was noted 2¼ miles east of Sabela (sheet 118). This contains abundant large prisms of augite, the maximum extinction noted being c : $\mathfrak{c}$ =53°; besides tremolite and calcite, plagioclase, zoisite, quartz, sphene and tourmaline are present. The occurrence of tourmaline is accounted for by the nearness to the mass of Erinpura granite forming the frontier range. As will be seen, abundant pegmatite occurs in the rocks in this neighbourhood. A peculiar amphibolitic type (34/227, 16182) occurs three miles south of Thandiberi; this has a granulitic aggregate of hornblende, quartz, felspar and epidote with apatite, sphene and zircon. An actinolite-schist (34/228, 16185) was noted two miles E. S. E. of Sabela. This also contains iron-ore. Chlorite-actinolite-schists (34/252, 16217) were noted further to the south, *viz.*, north-west of Nawawas (sheet 119).

Biotite-epidiorites (34/237, 16198) occur in the vicinity of Babera Hill, 2,273 feet (sheet 119); these contain abundant biotite in addition to zoned plagioclase, pyroxene, hornblende and epidote.

Other regions.

The basic rocks associated with the Ajabgarh mica-schists of other areas in Sirohi possess similarities to the above described examples. The varieties noted vary from epidorites to amphibolites to actinolite-schists.

Basic Rocks, Pre-Erinpura-Granite in Age, associated with the Ajabgarh Calcic Rocks.

Not common in calcic rocks.

Basic rocks are much less frequently associated with the calcic rocks of the Delhis than is the case for the mica-schists. The reasons for this are no doubt mechanical, as was suggested by Dr. A. M. Heron for the corresponding scarcity of basic rocks in the Alwar quartzites

(*see* p. 36). They occur in force in the calcic rocks near Sabela (sheet 118) and in the hills to the north and north-east of that village.

Occurrences.

Very few basic rocks are associated with the calcic rocks on sheet 119, except in the band of these rocks east of the Ramserji quartzite.

Basic rocks are quite common in the calcic types on sheet 97, especially in the vicinity of Jambuni, Baro and Bore; they are again common in the Ghoratankri-Deri area. A specimen of an epidiorite (36/780, 17585) from the last area shows traces of the ophitic structure of the original doleritic rock, though most of the augite is altered to hornblende. It might be that this rock is younger than the other types and is really to be correlated with the Kui and Chandrawati gabbros, similar rocks occurring in the hills in the vicinity of Bhainsasing.

Thin contorted bands of basic rocks occur in the limestones about half a mile south-west of Dhanwau (sheet 96, north of Abu Road). A specimen of one of these (36/159, 17137) is a typical hornblendic *garbenschiefer*[1] in appearance. The hornblende in this rock has the following pleochroism :—

$\mathfrak{a}$=light yellow-green.
$\mathfrak{b}$=light green,
$\mathfrak{c}$=light blue-green.
Absorption :— $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$

Other minerals noted were quartz, phlogopitic mica, chlorite, calcite, felspar and magnetite, the presence of the calcite being due to the associated calcic rocks.

Basic Rocks, Pre-Erinpura-Granite in Age, associated with the Aravallis.

Mention has already been made of the basic rocks occurring in the Aravallis in the extreme north-western corner of sheet 118.

Hybrid rocks.

These have been very severely metamorphosed and the original basic rocks appear to have derived certain acidic material from the metamorphosing agent, the Erinpura granite. The usual product is gneissic in appearance but all gradations can be seen in the field from a true amphibolite to one in which the amphibolitic character is almost entirely lost.

[1] A. Osann, 'Rosenbusch's Elemente der Gesteinslehre', Stuttgart, p. 693, (1923).

Analyses by Mons. F. Raoult of two specimens of the hybrid rocks are given in Table I, an analysis of the Erinpura granite, also by Mons. Raoult, being given for comparison. The specimens 25/469 and 25/470 are hybrid types occurring at Kawa in Idar State.[1]

Analyses.

TABLE I.

	36/68	36/69	34/215	25/469	25/470
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2 . .	50·42	47·64	71·48	63·54	57·20
TiO_2 . .	0·80	1·96	0·59	1·53	1·70
Al_2O_3 . .	24·18	17·45	13·35	14·28	14·78
Fe_2O_3 . .	1·91	3·03	0·06	2·68	2·12
FeO . .	2·55	5·11	3·83	5·24	7·43
MnO . .	0·18	0·26	0·09	0·11	0·13
MgO . .	1·52	5·22	0·33	1·02	3·23
CaO . .	4·92	9·02	1·40	4·38	6·48
Na_2O . .	9·89	7·27	2·73	1·98	2·25
K_2O . .	2·67	2·24	5·43	3·90	3·00
H_2O—108° C. .	0·20[2]	0·24[2]	0·22	0·09	0·11
H_2O+108° C. .	0·69[2]	0·94[2]	0·57	0·91	1·39
ZnO_2 . .	..	..	..	0·01	0·01
CO_2 . .	..	..	*trace*	..	..
P_2O_5 . .	0·28	0·22	0·07	0·24	0·32
Cl . . .	..	..	..	*trace*	..
Total S (as SO_3)	..	..	..	0·05	0·05
Cr_2O_3 . .	..	..	..	..	0·01
BaO . .	..	..	..	0·07	0·05
SrO . . .	..	..	..	*trace*	*trace*
TOTALS .	100·21	100·60	100·15	100·03	100·26
Specific gravities	2·695	2·955	2·673	2·83	2·87

36/68 (17036). Hornblende-biotite-garnet-rock, one mile west of hill station 1,771 feet (sheet 118) (F. Raoult).
36/69 (17037). Amphibolite, same locality (F. Raoult).
34/215 (16237). Erinpura granite, Trevor Tal, Mount Abu (sheet 96) (F. Raoult).
25/469. Kawa hybrid, Kawa, Idar State (W. A. K. Christie).
25/470. Kawa hybrid (W. A. K. Christie).

[1] C. S. Middlemiss, *Mem. Geol. Surv. Ind.*, XLIV, pp. 134-137, (1927).
[2] ±105°C. and not ±108° C.

Variation diagram.

In Figure 3, the percentages of the constituent oxides have been plotted as ordinates against the percentages of silica as abscissæ. The alumina percentages taken are the actual figures less 12·00 per cent. Ferric oxide has been converted to equivalent ferrous oxide and added to the ferrous oxide content, the resultant totals being plotted. The unbroken lines which join the plotted percentages of like constituent oxides show the lateral variation of these Sirohi rocks. Broken lines which show the lateral variation of the Kawa hybrid types have been given for the purposes of comparison, the percentages of the parent Kawa olivine-dolerite (26/464) and Kawa granite (26/514) being inserted.[1]

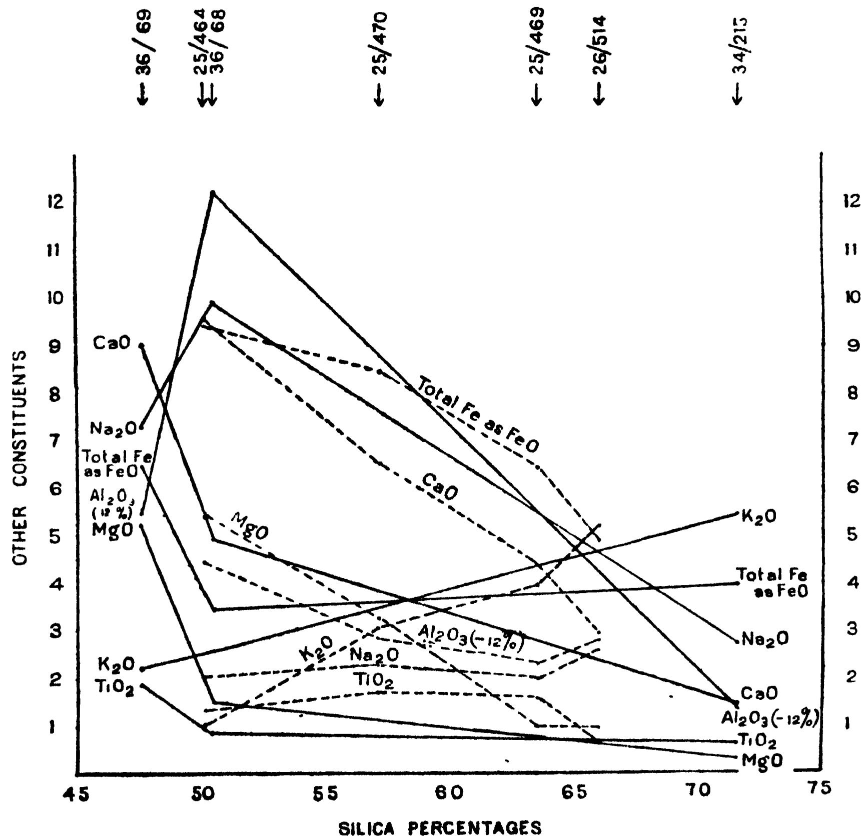

FIG. 3.—Variation diagram showing the variation of the percentages of the constituent oxides of the Erinpura granite and certain hybrid rocks it formed in Sirohi (unbroken lines), and of the Idar granite and hybrid rocks from Kawa, Idar State (broken lines).

[1] C. S. Middlemiss, *op. cit.*, p. 136.

The striking feature of the analyses in Table I is the high percentage of soda in the hybrid rock (36/68). One would expect the percentage of soda (9·89) in 36/68 to be about the same as that (7·27) in 36/69. The percentage of alumina (24·18) in 36/68 is also higher than that (17·45) in 36/69 though one would expect the contrary to hold. The high soda content in 36/68 is borne out by the occurrence in the section (17036) of a distinctly sodic amphibole and by the abundance of acidic plagioclase. The abundant presence of alumina shows that the assimilation is not merely the simple case of digestion of a basic rock by an invading granite, but that probably some aluminous sediments were also incorporated with the basic rock. The lateral variations of the constituent oxides in the Kawa case are much smoother and truer to type than for the more complex Sirohi example.

Conclusions.

Middlemiss' rocks are much younger than the Sirohi types, being derived from the interaction of an olivine-dolerite with the Idar granite, the basic rock being younger than the granite and both unmetamorphosed. The types occurring in Sirohi are due to the action of a granite upon older basic rocks, possibly also with sediments the hybrid types being formed under considerable pressure and being completely metamorphosed.

Under the microscope, the acidic hybrid (36/68, 17036) is seen to contain abundant pale brownish yellow garnets, sodic hornblende, quartz, plagioclase, orthoclase, biotite and sphene. The pleochroism of the biotite is :—

Mineralogical contents.

$\mathfrak{a}$=light greenish yellow,

$\mathfrak{b}$=dark olive-green,

$\mathfrak{c}$=dark olive-green.

Absorption :— $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$

It contains many small inclusions of ? rutile,[1] regularly arranged; it also exhibits pleochroic haloes around irregular zircon crystals. There is one irregular crystal in the section; this has a high refractive index, low birefringence and is biaxial, negative, and possesses a very small optic axial angle.

The amphibolitic type (36/69, 17037) contains hornblende, green diopside grading into augite, biotite similar to the previous section,

[1] O. Mügge, 'Rosenbusch's Mikroskopische Physiographie der Mineralien und Gesteine', Stuttgart, I, Pt. 2, p. 578. (1927).

sphene, iron-ore and apatite. A good example of zoning in diopside is shown in figure 4 of Plate 10.

Basic rocks are very common in this Sirohi-Erinpura tract. Epidiorites (17018) crop out in the vicinity of Sirohi, stretching towards Danta. These contain hornblende, with simple twins, presumably on (100), and diallage-augite, with quartz, felspar, iron-ore and abundant small prisms of apatite.

Amphibolitic rocks occur in the vicinity of the Undwaria conglomerate. A specimen (20903) collected by Dr. A. M. Heron from three miles east of Tokra (sheet 96) is composed of hornblende, felspar, iron-ore, chlorite and epidote.

Sindret-Undwaria tract.

One mile south-east of Balda (sheet 95), amphibolitic rocks (42/308, 21224) occur which are composed chiefly of hornblende with diopside, felspar and quartz. Further south-west in this same region, other occurrences are met with. At times these rocks possess a definite schistose structure (42/313, 21229; 21185), being composed of bundles of ? tremolitic hornblende prisms with quartz, felspar and iron-ore; at others the schistosity is not well defined (42/314, 21230), these varieties usually possessing a greater amount of plagioclase felspar. Somewhat similar rocks are found $1\frac{1}{2}$ miles E. S. E. of Nagani (sheet 96), a specimen (42/175, 21065), showing hornblende and biotite with abundant plagioclase felspar. The amphibolitic rock is intruded by quartz-felspar-tourmaline-pegmatite of Erinpura-granite age and also by a sheared epidiorite (42/172, 21066) mentioned in Chapter VII (*see* p. 100).

Dodia-Malgam tract.

Basic rocks are common near Amlari (sheet 95) in the isolated outcrops forming the first two series. These, however, have been provisionally ascribed to the post-Erinpura-granite basic phase. This is also true of the basic rocks in the Motagaun-Haliwara remnants. Pre-Erinpura-granite basic rocks are uncommon in the schists of the Anadra-Mandar area. In certain basic rocks occurring near Perwa (sheet 96), metamorphism has not been intense, but the usual type (17620) shows abundant tremolitic hornblende, the centres of which are composed of a faintly pleochroic enstatitic pyroxene with lower birefringence and higher refractive index and with straight extinction.

Dantral-Kankodara and Motagaun-Haliwara remnants and Anadra-Mandar area.

CHAPTER VI.

THE ERINPURA GRANITE AND ITS ACCOMPANYING APLITES AND PEGMATITES.

Nomenclature and Distribution.

Nomenclature.

The name 'Erinpura granite' originated from La Touche,[1] the type area being the hilly country in the vicinity of Erinpura. He did not recognize it further west than Erinpura but mentioned that it stretches south into Sirohi. La Touche described the Erinpura granite as an exceedingly coarse granite, the felspar crystals of which are frequently three or four inches in length, the other constituents, quartz and mica, being proportionately large. He noted that it is foliated along lines parallel to the junction with the schists and that it includes fragments of these; also in some cases the rocks in contact with the granite, *e.g.*, the Sarangwa marble, have been altered. It will be seen that this Erinpura granite is not really a granite but an adamellite. As the term Erinpura granite has been used now for some 29 years, it has been decided to retain it in its general sense.

Distribution.

The Erinpura granite covers by far the largest area of any rock in Sirohi State. The *massif* of Mount Abu is almost entirely composed of it, the granite continuing unbrokenly to the type area of Erinpura in the north and to Palanpur State in the south. It forms a number of isolated outcrops in the eastern part of Sirohi which may be designated for descriptive purposes the Moras, Waloria, Bhula, Bhamoria and Gorsa outcrops. There is a very large spread of Erinpura granite in the western part of the State, which may be termed the Kalandari-Dantrai outcrop; isolated exposures, the Magriwala-Mandar outcrops, also occur here.

Intrusive nature of Erinpura granite.

The Erinpura granite forming the Abu *massif* has been intruded at the junction of the Aravallis with the Delhis; the outcrops in the eastern part of the State

[1] T. D. La Touche, *Mem. Geol. Surv. Ind.*, XXXV, p. 18, (1902).

occur as intrusions in Delhi rocks; and the outcrops in the western part of the state occur as intrusions in the Aravallis.

There is no possible doubt that the Erinpura granite and its accompanying aplites and pegmatites are intrusive into both Aravalli and Delhi rocks. Various injection rocks and hybrid types have already been described. Roof-pendants of all sizes and descriptions have been noted. Included fragments of Delhi and Aravalli rocks are common. Contact metamorphic products upon large and small scales are frequent. The mechanics of intrusion of the granite forming the *massif* of Mount Abu will, however, be discussed later in this chapter (*see* pp. 74-76).

Mount Abu.

General description of Mount Abu.

Mount Abu is long and narrow, but the top spreads out into a picturesque plateau about 12 miles in length and between two to three miles in breadth. The top of Abu can be conveniently divided into three undulating areas:—the northern area lying to the north-east of Guru Sikkar, the highest peak, some 5,650 feet above sea-level, containing the villages of Ser and Utraj; the central area in which lie the villages of Oria, Achalgarh, Jawai, etc.: and the southern area, with Salgaon, Abu, Hetamji, etc. The southern area is the site of the civil and military station and in it lies the lake Nakki Tal, 3,771 feet above sea-level. High peaks rise on all sides of these undulating areas with their succession of hills and dales, and the slopes of the whole mountain, especially on its western and northern sides, are extremely precipitous. Dilwara, in the northern part of the southern region, is the site of the most wonderful Jain temples in the world (*see* p. 158).

Weathering of the granite.

The variation in grain-size and mineralogical contents of the granite has its effect upon the weathering of the rocks. Smooth rounded slopes are the commonest feature and these make the ascent of some of the bordering peaks a perilous undertaking. Undercutting by solution and weathering, assisted by wind erosion, is very noticeable, sometimes resulting in fantastic shapes and designs which make prominent landmarks. Caverns and large holes are common and porphyritic crystals of felspar, which have been more resistant to the agents of denudation than the other mineralogical constituents of the rocks, show out very frequently on weathered surfaces.

Strike.

There is a remarkable parallelism between the eastern and western boundaries of the Erinpura granite forming the *massif* of Mount Abu, both coinciding with the general strike of the Aravalli and Delhi rocks and the main foliation direction of the granite, *i.e.*, N. N. E.–S. S. W.

Petrological Notes on the Erinpura Granite of Mount Abu.

Abu Bazaar.

The granite in the neighbourhood of the Abu Bazaar (34/223; 16230) appears as a hornblendic gneiss, specific gravity 2·66, containing abundant hornblende, quartz, felspar, a little biotite, sphene, zircon and some iron-ore. The pleochroism of the hornblende is :—

$\mathfrak{a}$ =light brown,
$\mathfrak{b}$ =dark green,
$\mathfrak{c}$ =dark green.

Absorption :— $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

Both orthoclase and plagioclase are present, the former in beautiful eutectic intergrowths with quartz. Microperthite also occurs. The felspars are slightly clouded but an albite twin was found by Federov stage methods to have individuals of 35 and 40 per cent. An in composition.[1] The percentage of silica in this rock was determined by Mr. L. R. Sharma as 65·62. The sphene is very interesting as it surrounds centres of ilmenite. There is a very well marked gneissic banding in this area.

Between the Bazaar and Sunset Point, the colour of the felspars changes from white to flesh-coloured and the granite become fine-grained (34/222, 16231) and has slightly less specific gravity (2·63). Fluorite occurs in the section. Occasional bands of biotite can be seen in the soil, but these are probably the remnants of decomposed bands of pegmatite.

South-east of Nakki Tal.

About 1½ miles south-east of Nakki Tal, the granite (34/221, 16232) shows bluish-coloured quartz, large crystals of felspar, with hornblende and biotite, largely altered to chlorite, in a finer-grained groundmass (specific gravity, 2·63). Flourite is present. One section of orthoclase appears to be positive in optical character, but on account of the large value of 2 V, it is impossible to state with certainty whether the section is perpendicular to $\mathfrak{a}$ or to $\mathfrak{c}$. This

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 167, (1931).

variety of rock forms the hills around hill station 4,596 feet and those towards Gau Mukh.

Hetamji.

Included fragments of amphibolitic rocks are common near Hetamji and Arna. These (34/220, 16233) show prisms of hornblende with fine-grained quartz and felspar. Along the old road south-west of Hetamji, the granite (34/219, 16234) becomes more biotitic and gneissic, the quartz loses its bluish colour and the groundmass is finer-grained (specific gravity, 2·63). An albite twin has individuals of compositions 42 and 35 per cent. An [1] A small quantity of fluorite is present. Near the Abu High School the gneissic structure is lost, the rock being a normal pinkish-coloured granite (34/218).

Anadra Gate and Dilwara.

Near Anadra Gate, the quartz is bluish in colour but the rock (34/217, 16235) is otherwise a normal biotite-granite (specific gravity, 2·60) with no foliation. The Erinpura granite on the back road to Dilwara from Nakki Tal is strongly foliated (34/216, 16236) and is quarried here for use as a building stone. The section shows abundant biotite and microperthitic intergrowths are common. Xenolithic relics of mica-schists were noted in the quarry.

Trevor Tal.

Proceeding north to Trevor Tal, one notes that the granite (34/215, 16237) is similar in appearance to that in the vicinity of Abu Bazaar, but contains abundant biotite and no hornblende. This specimen was selected as being as nearly as possible typical of the Erinpura granite of Mount Abu and was analysed with the results given on page 59. The section shows sphene with ilmenitic centres, in addition to quartz, plagioclase, perthite and biotite.

Salgaon.

To the south-east, in the vicinity of Salgaon, the usual type of rock met with (34/214, 16238) shows large phenocrysts of microcline, with perthitic intergrowths, and quartz, set in a finer-grained groundmass of the same minerals and plagioclase. A little biotite and hornblende are present; fluorite occurs. The large phenocrysts of felspar show out on the weathered surface of the rock.

Central area of Mount Abu —Oria.

The variations in grain and structure of the Erinpura granite are equally apparent in the northern and central areas of the mountain. On the road from Dilwara to Oria, specimens show large phenocrysts of microcline with varying amounts of biotite,

[1] A. L. Coulson, *Rec. Geol, Surv. Ind.*, LXV, p. 167, (1931).

and generally possess a definite foliation. At the Oria *dâk* bungalow, however, there is no foliation and the rock (34/212, 16240; 34/209, 16243) is conspicuous by its coarseness of grain and the abundance of ferromagnesian minerals, hornblende being present in addition to biotite. There is a fair amount of calcite and fluorite; zircon is found also (specific gravities, 2·65 and 2·61). Foliation is again apparent west of the bungalow and the stone is quarried. Fluorite is seen in thin section (16245). Small prisms of hornblende occur in a biotitic variety of the granite (34/208, 16244), 1½ miles W. N. W. of Oria.

Achalgarh.

The rock forming Achalgarh Hill (34/213, 16239) is generally finer-grained than the Oria types; it has a specific gravity of 2·64. It is interesting to note the occurrence of an albite-Ala B complex of composition 32 per cent. An in this rock.[1] Abundant fluorite and muscovite were noted.

Guru Sikkar.

Guru Sikkar, the highest peak of Abu, is formed of a porphyritic biotite-granite (34/211; 16241; specific gravity, 2·66) with some hornblende, fluorite and sphene with ilmenite centres (*see* Plate 11, fig. 3). Just below the summit, there is a local variation of a finer-grained rock (34/210; 16242), also with fluorite; but the bulk of the hill is composed of the porphyritic variety. There is practically no path to Utraj and Ser from Guru Sikkar but as far as could be seen, the northern area of Abu is also composed of variations of the Erinpura granite.

Composition of the Erinpura Granite of Mount Abu.

Analyses.

An analysis by Mons. F. Raouït of a specimen (34/215) of grey Erinpura granite from Trevor Tal is given in Table II, which also contains, for ready comparison, an analysis of a specimen of red Erinpura granite from Waloria (sheet 118) in the Sirohi-Udaipur frontier region. The other analyses in the table are taken from Hatch's 'Textbook of Petrology, I, Petrology of the Igneous Rocks',[2] and Clarke's 'Data of Geochemistry'.[3]

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 183, (1931).
[2] F. H. Hatch, *op. cit.*, London, pp. 175, 179, (1914).
[3] F. W. Clarke, *U. S. Geol. Surv.*, Bull. 695, p. 438, (1920).

TABLE II.

	34/215	34/246	Mean of 34/215 and 34/246	A	B	C	D
	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.
SiO_2 . . .	71·48	79·06	75·27	71·90	76·01	71·25	68·97
TiO_2 . . .	0·59	trace	0·29	0·35	..	..	..
Al_2O_3 . .	13·35	11·34	12·35	14·12	13·47	13·03	14·80
Fe_2O_3 . . .	0·06	0·65	0·35	1·20	1·54	1·29	3·29
FeO . . .	3·83	0·21	2·02	0·86	..	0·34	..
MnO . . .	0·09	*trace*	0·05	0·05	..	..	..
MgO . . .	0·33	..	0·16	0·33	0·06	0·38	1·15
CaO . . .	1·40	0·28	0·84	1·13	0·54	2·61	3·82
Na_2O . . .	2·73	2·44	2·59	4·52	2·32	2·25	2·46
K_2O . . .	5·43	5·89	5·66	4·31	5·57	3·09	4·53
H_2O—105°C .	0·22	0·33	0·27	0·18	0·56	0·82	0·70
H_2O+105°C .	0·57	0·32	0·45	0·42			
CO_2 . . .	*trace*	..	*trace*	0·21	..	..	..
P_2O_5 . . .	0·07	..	0·03	0·11	..	..	..
Other constituents	..	..	..	0·16	0·12	0·13	..
TOTALS .	100·15	100·52	100·33	100·35	100·10	100·19	99·72
Specific gravities	2·673	2·603	2·638	..	..	..	..

34/215. Grey Erinpura granite, Trevor Tal, Mount Abu (sheet 96), Sirohi State, Rajputana (F. Raoult).
34/246. Red Erinpura granite, east of Waloria (sheet 118), Sirohi State, Rajputana (F. Raoult).
A. Granitite, near Floressant, Colorado, U. S. A. (W. F. Hillebrand).
B. Potash-granite, Cairngorm, Central Highlands, Scotland (W. Mackie).
C. Adamellite, Abriachan, Loch Ness, Scotland (W. Mackie).
D. Adamellite, Landsberg, Vosges Mountains (Unger).

Study of analyses.

The analysis of the Trevor Tal Erinpura granite (34/215) indicates a rock more correctly termed an adamellite. The silica percentage (71·48) is comparable with that (71·25) of the adamellite from Abriachan; but the alumina (13·35) is more comparable with that (14·80) of the adamellite from Landsberg. The granitite from Flourissant contains microcline, albite, quartz and biotite and its silica (71·90) and alumina (14·12) contents bear some relationship to those in the Trevor Tal specimen. The analysis of the Waloria potash-granite will be discussed in detail later in this chapter (*see* pp. 62-65).

Specific gravity.

The mean specific gravity of nine specimens of Erinpura granite from the *massif* of Mount Abu is 2·63.

Composition of felspars.

The mean composition of six individual felspars forming twins or complexes is 36 per cent. An. The Federov stage results for the felspars support the results of the analyses in indicating that the Erinpura granite should more correctly be termed the Erinpura adamellite from its occurrences in the *massif* of Mount Abu. This will be seen to be true for most other regions besides Abu; but in certain exposures, as at Waloria and Bhamoria, the Erinpura granite is a potash-granite.

Abu type of Erinpura granite really an adamellite.

The Erinpura granite in the Abu region is biotitic, with subordinate hornblende. Its usual colour is grey. The largest felspars are microcline or orthoclase, sometimes inches in length and usually containing perthitic intergrowths of acidic plagioclases. Graphic and micrographic intergrowths of quartz and potassium felspars are rare. Plagioclase is present to an equal extent with the potassium felspars. Quartz is abundant. The commonest accessories are fluorite, iron-ore, sphene and zircon. It will be noted that fluorite occurs in ten of the sixteen thin sections described above. As will be seen later, this mineral is also characteristically present in the Erinpura granite of the plains. It is worthy of note that Dr. Heron[1] found fluorite to be an unusual accessory in the post-Delhi granite of North-Eastern Rajputana. He does not record it in the post-Delhi granite bosses of Western Jaipur,[2] although these are all examples of the Erinpura granite, but a long distance to the north-east.

Erinpura Granite Between Abu and Erinpura.

The variations in the nature of the Erinpura granite forming the ranges and plains in the area north-east of Mount Abu are similar to those found in the Abu *massif*, with which it is perfectly continuous.

Variations similar to Abu massif.

Residuals of Erinpura granite in the Idar granite occur between hill station 2,181 feet and the main mass of Erinpura granite. The

[1] *Mem. Geol. Surv. Ind.*, XLV, p. 93, (1917).
[2] *Rec. Geol. Surv. Ind.*, LIV, pp. 379-382, (1923).

large residual north-west of Attaji ka Mul (sheet 95) is composed of very porphyritic crystals of quartz, felspar and biotite, the felspars being as much as two to three inches in length (36/78, 17056). The strongly foliated type found at Attaji ka Mul (36/79, 17057) resembles the normal Abu exposures but also contains a fair quantity of hornblende and sphene. The Erinpura granite cropping out in the vicinity of the village of Danta (sheet 95) is profusely intruded by a series of felspar-porphyry dykes (*see* Chapter IX); it is generally very coarse-grained and grey in colour.

Biotite contents variable.

The amount of biotite in the Erinpura granite is increased near its junction with the phyllitic rocks east of Sirohi; the foliation of the rock 'dips' strongly E. S. E. The more biotitic the rock, the softer and more easily weathered it becomes, forming low hills. The hills generally are high near Rarbor (sheet 117), where little biotite is found, but felspar is abundant, the rock being less easily weathered. A short distance away, however, in the neighbourhood of Dharmano, the rock is once more very biotitic. Large 'eyes' of felspar are conspicuous near Godana; these (36/67) usually contain a certain amount of biotite.

There is a relative abundance of pegmatite in the Erinpura granite of this region.

Hills near Andor.

There is some doubt as to the exact age of the porphyritic granite (17040) forming the hill one mile S. S. W. of Andor (sheet 94). This has been mapped as Erinpura granite, though it is possibly a porphyritic form of Idar granite (*see* p. 115). It contains abundant inclusions (17039). Another doubtful porphyritic rock was noted in the southern extremity of the ridge one mile west of Andor, its relations with the Idar granite forming the rest of the ridge being obscure. This rock (36/70, 17038 A and B) contains large Baveno twins of orthoclase, its ferromagnesian mineral being a strongly pleochroic biotite.

Moras Outcrop.

The outcrops of Erinpura granite in the region east of the Mount Abu-Erinpura region will be now described. The first of these,

Sirohi-Udaipur frontier range.

cropping out in the north-eastern corner of the State, forms the high hills, east of Pindwara (sheet 118) and stretching south to Moras (sheet 119), which mark the frontier between Sirohi and Udaipur

The metamorphism of the mica-schists in this region has been very intense; it was accompanied by abundant injection of pegmatite, the result being that in the field it is very often a matter of considerable difficulty to decide whether a given specimen is an injection-gneiss or a strongly foliated granite (16181). A specimen of granite from Moras (34/240, 16203), of specific gravity 2·69, contains abundant large crystals of microcline, with biotite as the chief ferromagnesian mineral; epidote is present in fair quantity.

Waloria and Bhamoria Outcrops.

Locality.

It is convenient for descriptive purposes to consider the Waloria and Bhamoria outcrops together. The former occurs as a large mass south-east of Waloria, culminating in the frontier peaks of Bormal (2,460 feet) and hill station 2,809 feet. The latter outcrop is on the borders between Idar and Sirohi and between Danta and Sirohi (sheets 119, 120 and 97), and includes the hill station of 3,080 feet.

Different from Abu type of Erinpura granite.

The correlation of these outcrops with the Erinpura granite has been a matter of considerable discussion, inasmuch as the physical appearance of the granite differs considerably from the types described in the foregoing pages. Hand specimens (34/246, 16209; 34/247, 16210; 34/248, 16211; 34/249, 16212; 36/774, 17578; 36/775, 17579 and 36/776, 17580) indicate a flesh- to pink- or red-coloured rock with strong foliation; a definite vertical jointing assists the formation of steep gorges, totally different from what are found in the Erinpura granite of other parts. Under the microscope, the granite is seen to be composed of microcline perthite, quartz and plagioclase (little) with subordinate biotite in the Waloria specimens and subordinate hornblende and biotite in the Bhamoria rocks; epidote and sphene are common accessory minerals. The grain-size varies, being at times coarse, at others, fine. The subordinate quantity of ferromagnesian minerals and plagioclase is very noticeable.

Composition.

An analysis of 34/246, from east of Waloria, has been given previously (*see* page 59). The percentage of silica in this granite was determined independently by Mr. L. R. Sharma as 76·85 (79·06 by Mons. F. Raoult); its specific gravity is 2·61. A comparison of the analysis of 34/246 with that of 34/215, the Erinpura granite (really adamellite) from Trevor Tal, shows there is considerable difference in composition

between these two rocks. The Waloria type is far more acidic. Its silica content is 79·06 compared with 71·48. A glance at Table II shows its similarities to the potash-granite from Cairngorm; but it is even more acidic than that rock. It is, however, best described as a potash-granite. The relative absence of ferromagnesian minerals in the hand specimens and thin sections may be compared with the abundant presence of biotite, with subordinate hornblende, in the Erinpura granite of Abu. Also, as noted before, plagioclase is sufficiently abundant in the Abu variety to warrant the rock being termed an adamellite.

All this does not mean that the two types, Waloria and Abu, are parts of different original magmas. The composition of the Erinpura granite is known to vary greatly; this is not to be wondered at when the immense size and wide distribution of its occurrences are taken into account. The rate of cooling in certain parts has been extraordinarily slow, allowing the formation of large crystals and of differentiates of varying composition; the cooling in other parts has been rapid, or the magma has been subjected to pressure and there has been no chance of differentiation taking place.

Dr. Heron's field notes.

Dr. A. M. Heron has obtained conclusive field evidence of the interrelationship of the Waloria type with the Abu type of Erinpura granite. The following is a quotation from his notes upon a traverse made in the frontier region of Udaipur and Sirohi:—

'The red granite between Perlai and Paba appears to form a great sill, dipping to the north-west in concord with the "grain" of the country, and is foliated in the same direction. I crossed it from Perlai to Paba over the cluster of hills at the trijunction of Mewar, Idar and Sirohi. Long before the main granite is encountered, sheets of red microgranite or aplite are met with in the calcareous series, foliated and dipping with the calcareous rocks, calc-gneisses and calciphyres. It is practically devoid of mica, and so perfectly and so straightly foliated that it might almost be called "slaty" or "bedded". Though hard, it breaks readily into small rectangular blocks and weathers with sharp edges, unlike granite, but more like felsite, which it resembles in appearance. It is the same as the pink felspathic granulites mentioned above.

'Passing into the main granite, at its base according to its position, but not necessarily its stratigraphic base (*see* below), the grain of the rock becomes macroscopically visible, but it is still fine-grained and compact, and very little mica is seen until the top is reached. It does not weather into rounded "tors", in the manner typical of granite under insolation, but disintegrates into angular debris, and forms blocky outcrops more like those of quartzite than granite. Where it is coarsest, these blocks have rough surfaces showing the foliation by differential etching on weathering.

'At the top of the main sheet, biotite becomes relatively abundant, and on the track leading from Paba to Bori ki Bhuj, just south of the northern edge of Central India and Rajputana sheet 120 (Bombay sheet 143), the red granite and the Erinpura granite are found in close juxtaposition, and are here very alike (except in their colour), even in the manner in which they weather. The presence of biotite in the red granite appears to have a weakening effect on it, as regards its resisting power against weathering, for in the ridge it is not micaceous, and the micaceous portion lies in low ground along the north-western base of the ridge. As the entire formations here are very probably inverted, as we are presumably near the north-western (inverted) flank of the Delhi synclinorium. What I have referred to as the top and bottom of the main sheet of the red granite are quite likely the bottom and top stratigraphically, and on this assumption the red granite is more biotitic, *i.e.*, more basic, towards the actual base of the sheet.

'At first I thought that there was a complete transition between the two granites, but a section just north of the southern edge of Central India and Rajputana sheet 119 casts a little doubt on their perfect and mutual gradation of one into the other, though it very nearly happens.

'Immediately west of the most southerly houses of the scattered village of Bori ki Bhuj, both granites are exposed in a little scarp, the grey Erinpura granite above and the red (or here pink) granite beneath, both well-foliated, both biotitic, and with much the same grain. The latter is yellowish in places, this probably being a bleaching effect of weathering.

'The junction between the two is not sharp, such as it would be if the red granite had been intruded into the Erinpura grey granite while the latter was in a solid state, but appears as if the two had both been equally fluid when they came together, or as if they were differentiates *in situ* from the same magma.

'The several varieties of the red granite and its pink pegmatites and sheets of fine-grained felsite-like aplite, can be matched by variations of the post-Delhi granite in northern Rajputana (Jaipur and Ajmer-Merwara), just as the various forms of the Erinpura granite here are represented in different intrusions in northern Rajputana, and there every gradation between the two has been seen. The red granite is here just as much foliated, and in places even more so, than the Erinpura granite, and differs from it only in the colour of the felspar, and in being, as a rule, less biotitic, though not always.'

Origin of Waloria and Bhamoria types.

Thus it may safely be concluded that the Waloria and Bhamoria outcrops originated from a granitic magma more acidic than the average composition of the large outcrops of the Erinpura granite. This more acidic magma is considered as being an acidic differentiation product of the large original magma which gave rise to both types; the grey normal Erinpura granite (adamellite) is slightly more basic than the original magma; the red Waloria potash-granite is distinctly more acidic than the original magma. The Waloria and Bhamoria exposures resemble the Idar granite rather than the grey Erinpura granite in *composition;* they differ of

course in age, the Idar granite being far younger than the Waloria and Bhamoria types, which must be considered as being to all intents and purposes contemporaneous with the grey Erinpura granite.

Bhula Outcrop.

The Bhula outcrop lies more or less between the Waloria and Bhamoria exposures (but slightly 'staggered'). It, however, differs entirely from these in appearance, resembling the grey Erinpura granite of Abu and being even more basic than this. A gneissic specimen (34/250, 16214) from Nawawas (sheet 119) shows abundant biotite, epidote (pleochroic, colourless to light greenish yellow), felspar and quartz. The abundance of biotite has resulted in the rock being easily weathered, with the consequence that the granitic exposures here form the low-lying ground, calcic rocks and amphibolites forming the hilly country.

Appearance resembles Abu types.

A specimen (34/255, 16221) from Bhula (sheet 119) contains diallage and chlorite in addition to the minerals noted above. The more basic character of the rock is evidenced in the composition of the felspars. Determination by Federov stage methods of the individuals forming albite twins and pericline twins gave a composition of 40 per cent. An. A section (16224) of the Erinpura granite from south of Sanwara (sheet 119) also shows small inclusions around which are pleochroic haloes. The Erinpura granite is very epidotised in the vicinity of Mandwara (16223).

More basic than the Abu and Waloria types.

The rock (34/234, 16195) in the isolated exposure of Erinpura granite near Wasa (sheet 119) resembles the Abu types, containing abundant biotite, but it also shows a fair amount of muscovite.

Wasa.

Gorsa Outcrop.

The bow- or boomerang shaped outcrop of Erinpura granite in the vicinity of Gorsa (sheet 97) resembles in its field relations the Bhamoria intrusion as described in the quotation from Dr. Heron's notes. There is no doubt that this outcrop is that of a sill-like sheet of granite which appears to have been intruded through the calcic rocks.

Field relations.

Hand specimens and sections (36/783, 17588) of this Gorsa granite, taken from $1\frac{1}{4}$ miles south-west of the hill station 2,773 feet (sheet 97), indicate a fine grained rock composed of quartz, orthoclase and abundant plagioclase, with subordinate hornblende and biotite and accessory iron-ore and epidote. A section (17590) of a similar specimen from half a mile south-west of hill station 2,842 feet shows microcline; this occurs isolated from the main Gorsa outcrop. The texture of another isolated outcrop (36/785, 17591) at Sur Paga (sheet 97) is much coarser; abundant muscovite was noticed in the section.

Fine-grained rock.

In his 'Preliminary Note on the Geology of Danta State (N. Gujarat)', Mr. Sharma has mapped the Erinpura granitic masses in this region as microgranites and granite-porphyries. He states[1] that

N. L. Sharma.

'the microgranite masses are those of the Menagir ridge and near Padlio-ka-Chapra at the Danta-Sirohee boundary. The granite-porphyry rock is characteristic of Kotesar and Amba Mata areas'.

The author of this memoir originally regarded these rocks as being probably contemporaneous with the Jalor granite;[2] but he has since modified that view, now regarding them as variants of the Erinpura granite and not representatives of the much younger (Jalor or Idar) granite.

Variants of Erinpura granite.

Kalandari-Dantrai Outcrop.

The outcrop of Erinpura granite designated the Kalandari-Dantrai outcrop occurs as a very large spread in the western part of sheet 95 and in the north-western part of sheet 96. The tracts of Aravalli rocks occurring as isolated masses in the granite have been described in Chapter III. Besides being divided by these Aravalli rocks, the Erinpura granite in this region is profusely intruded by doleritic rocks which have no counterparts in the eastern part of the State, with the exception of the gabbros and dolerites occurring south of Abu Road (sheet 97). A fine suite of plutonic, hypabyssal and volcanic rocks of interesting characters intrude the Erinpura granite in the vicinity of Mundwara (sheet 95). These are described in Chapter VII. Granitic and acidic hypabyssal types, belonging to the Malani

Intruded by other rocks.

[1] N. L. Sharma, *Q. J. Geol. Min. Met. Soc. Ind.*, III, p. 25, (1931).
[2] *Rec. Geol. Surv. Ind.*, LXI, p. 132, (1929). N. L. Sharma, *op. cit.*, p. 27.

system, are especially numerous on sheet 95; these intrude the Erinpura granite and are distinctly younger than it (*see* Chapters VIII and IX).

Usual type of granite.

The usual type of Erinpura granite found in the Kalandari-Dantrai region is a grey coarsely crystalline rock (42/219, 21120) composed of quartz, orthoclase and microcline with perthite, plagioclase and biotite. Muscovite is frequently present. The biotite often exhibits abundant pleochroic haloes. Common accessories are fluorite, iron-ore and sphene. In contrast to the Abu types, gneissic structure is not generally well marked. Foliated types do occur, as, *e.g.*, 1½ miles N. N. W. of Akona (sheet 95), but they are not so common as unfoliated types. The Akona specimen (42/246, 21152) has a specific gravity of 2·68. It is associated with a finer-grained aplitic type (42/257, 21053).

Nagani.

The biotitic Erinpura granite (42/179, 21070) at Nagani (sheet 96) is interesting as the felspars are characterised by a greenish tint, due no doubt to sericitisation; perthitic intergrowths of orthoclase and acidic plagioclase are common. The granite in this region contains abundant undigested fragments of mica-schists, metamorphosed to granulites (42/178, 21069).

Dhan.

There is a fine-grained granite (42/181, 21073) just west of Dhan (sheet 96) containing abundant quartz, microcline and plagioclase, with biotite, muscovite, iron-ore and fluorite, which is associated with a coarser-grained type (42/182, 21074), the biotite of which contains numerous inclusions of fluorite and radioactive minerals. The junction between the two types is unfortunately masked by vegetation; but there seems little doubt that both are modifications of the Erinpura granite, the finer-grained type resembling the rock found in the Gorsa outcrop described previously and the coarser-grained variety resembling the normal Erinpura granite found in these regions (42/185, 21093; 42/204, 21103). Another specimen (21062) of fine-grained Erinpura granite was collected from three-quarters of a mile west of Sirori (sheet 96).

Junction between Idar and Erinpura granites.

The relationships of the granites occurring at the junction of sheets 76 and 96, forming Nandwara Hill and what may be conveniently termed the Jirawal hills, have been a matter of some difficulty. It will be seen from Plate 12 that part of the hills

here has been mapped as Idar granite, the remainder as Erinpura granite. It is at times hard to distinguish these granites from each other, this being especially so in the southern part of the hills in question. There is no doubt that the hills immediately north of Jirawal are formed of Erinpura granite. There is likewise no doubt that the hill stations 3,277 feet and 3,220 feet are formed of Idar granite. The boundary between the two granites here is definite; but that part of the boundary on sheet 76 is uncertain in view of the doubt of the nature of the granite forming hill station 1,180 (ap.) feet. A specimen (42/192, 21083) from here resembles the Idar granite in the field though graphic intergrowth of quartz and felspar does not occur in the section, and the biotite is very like that found in the Erinpura granite. Hill stations 2,280 feet and 1,945 feet are composed of Erinpura granite. Hence the boundary on the map cannot be far out, if at all so.

Jirawal.

The Erinpura granite (42/190, 21081) one mile south-west of Jirawal is of normal type, but two miles from Jirawal in the same direction, a brecciated type (42/191, 21082) was noticed. The brecciation was probably caused by local movement in the granite.

Variable presence of fluorite.

The Erinpura granite (21174) forming hill station 1,431 feet, 1½ miles S. S. W. of Siloi (sheet 95), contains abundant muscovite, with biotite but no fluorite. In a slickensided specimen of granite (42/279, 21187) from 1¼ miles S. S. W. of this village, however, fluorite is extremely abundant. The Erinpura granite (42/271, 21178) from 1¾ miles N. N. E. of Balda (sheet 95) shows brecciation.

Epidotisation of the granite.

The Erinpura granite is very frequently epidotised in the vicinity of dolerite dykes or basalts intruding it. The epidotisation is usually accompanied by a reddening of the felspars. One such example (42/267, 21173) was noted one mile south of Sarthara (sheet 95), the intrusive rock being a basalt (42/266, 21172).

Exfoliation of the granite.

It was frequently noticed that the Erinpura granite of the Kalandari-Dantrai outcrops exfoliated along surfaces which are apparently the junction between two types of granite of different texture. Thus fragments of a coarse felspathic granite were often noted on a smooth unbroken surface of a finer-grained type. As the surfaces of exfoliation are roughly spherical, it is possible that the cooling of the magma proceeded from centres, the concentric shells of rock

of different thickness and texture bearing evidence to the changes of conditions experienced during the crystallisation processes (also *see* p. 77).

Magriwala-Mandar Outcrops.

The outcrops in question occur in the south-western corner of sheet 96 and the south-eastern corner of sheet 76. Two sections of the Erinpura granite at Mandar (36/806, 17613; 36/805, 17614) show hornblende in addition to biotite, quartz, microcline, orthoclase and plagioclase with accessory iron-ore, apatite and sphene. Specimen 36/806 has a specific gravity of 2·68. The Erinpura granite (36/809, 17617) forming the isolated outcrop one mile E. N. E. of Rajpura (sheet 76) contains hornblende and biotite. The section bears some relationship to the Idar granite but as the rock is intruded by a doleritic dyke (36/808, 17616), similar to those described in the next chapter, the outcrop has been ascribed to the Erinpura granite. The rock has a specific gravity of 2·63. The granite outcrop (36/807, 17615) two miles south-east of Rohua (sheet 76) contains irregular masses of microcline intergrown with quartz, plagioclase and biotite.

Descriptive notes.

The Erinpura granite forming the hills near Magriwala (sheet 76) is similar to that (36/810, 17618) one mile W. S. W. of Awara (sheet 96), being a coarsely crystalline rock with abundant felspar.

Aplites and Pegmatites.

The Erinpura granite is accompanied by rocks which have the physical and mineralogical characters of aplites and pegmatites. Their distribution is very variable and their quantity and composition varies to a like extent.

It will have been noted that the Erinpura granite itself shows many modifications. The general occurrence on the plains is a coarsely crystalline rock which appears to have consolidated at a sufficiently slow rate to allow differentiation of the magma to take place. There was the formation of acidic and basic differentiates, using these terms with reference to the nature of the original magma. The granite is now exposed as a consequence of the extreme and long-continued erosion to which the overlying rocks were subjected. It is a justifiable conclusion that those parts of the granite now exposed which contain abundant pegmatite and aplite, were

Differentiation of the Erinpura granite.

formed at no great depths below the superincumbent rocks. It may also be concluded that the probabilities are that those parts of the granite relatively free from pegmatite were formed at relatively great depths from the top of the magma.

Scarcity of pegmatite on Abu.

It has been noted that the granite of the plains crystallised slowly. The granite forming the *massif* of Abu likewise crystallised slowly, but the magma was subjected to more pressure, with the consequent development in the rock of a general foliation. The highest point of Abu, Guru Sikkar, is some 5,650 feet above sea-level. The general height of the top of Abu is about 4,000 feet. The mean height above sea-level of the plains surrounding the mountain is approximately 900 feet. Thus the general difference in elevation between Abu and the plains may be considered as 3,100 feet. Accordingly one might expect that pegmatite would be very abundant on Abu compared with its distribution on the plains. This, however, is most certainly not the case. Pegmatite is relatively rare on Abu, being far less abundant than on the plains. It must naturally be concluded that on the top of Abu, some 3,100 feet above the plains, we find granite which appears to have characteristics such as would be found were that granite to occur much below the plains level. In other words, *on the top of Mount Abu, we are further from the roof of the batholith than if we were on the plains some 3,100 less in elevation.*

The explanation is, of course, simple. The Abu *massif* has been intruded as a steep-sided batholith, there being differential movement along its margins (*see* pp. 74 76).

True aplites rare.

Fine-grained acidic forms of Erinpura granite with aplitic characteristics have already been described. It is very rare, however, that true aplites are recorded, for most of these fine-grained forms contain sufficient ferromagnesian minerals to warrant their being termed fine-grained grantes or microgranites. It is true that muscovite may be present in an aplite, cut when there is in addition a fair quantity of biotite and hornblende, albeit the rack is still leucocratic in appearance, then the assignation of the term 'aplite' can be of use only as a convenient field description.

Origin of aplitic types.

These fine-grainad leucocratic rocks are considered as being acidic differentiates of the cooling Erinpura granite which have been intruded as a still fluid magma before the differentiation processes have had

time to produce a differentiate which, on solidification, would give rise to an aplite. Such junctions between these 'aplites' and the Erinpura granite as are visible in the field are not as a rule sharp, though they are distinct. Sometimes the aplitic rocks have a moderate extent, but generally they vary in thickness from a few inches to several feet, occurring as veins in the Erinpura granite. The usual minerals present are quartz and orthoclase, with muscovite and chlorite or biotite, and hornblende only very occasionally. A typical example is the specimen (42/247, 21153) from 1½ miles N. N. W. of Akona (sheet 95) mentioned previously (*see* p. 67).

A tourmaline-bearing specimen (42/205, 21104) from 1¼ miles north of Amlari (sheet 95) is of interest as the thin section shows doubtful topaz. This is the sole section in which topaz was recognized. The tourmaline occurs as rosettes in patches up to one inch in diameter, forming a rock of very distinctive appearance.

? Topaz.

The pegmatite accompanying the Erinpura granite may roughly be divided into two classes, the reef-quartz pegmatites and normal quartz-felspar pegmatites. The former form characteristic outcrops; the reef-quartz being more resistant than the rocks with which it is associated, the usual result is to give a white ridge visible from a great distance. Most of the pegmatite mapped (not shown on Plate 12) is of this kind. The reef-quartz pegmatites are composed almost entirely of quartz which is variable in purity and is frequently 'dirty' in colour. The outcrops vary in extent from mere 'plugs' to ridges over a mile in length. They are never of any great thickness, varying like the aplites from even less than an inch to several feet. The reef-quartz pegmatites are considered to be terminal acidic differentiation products, the quartz-felspar pegmatites being less acidic.

Two types of pegmatite.

The colour of the quartz-felspar pegmatites varies according to the colour of the felspar which is the dominant constituent. Generally it is white, but in certain districts the characteristic colour changes to reddish or pink. Dr. A. M. Heron noted in March, 1930, that the

Variable colour of quartz-felspar pegmatites.

'Erinpura granite has both pegmatites:—those with white felspar, and with pink, and dykes have been seen in which both white and pink occur. Auden has recorded both colours in the one felspar crystal.'

The pink colour is predominant in the south-eastern corner of the State in the vicinity of the Waloria, Bhamoria and Gorsa outcrops.

Petrological notes.

The following brief description of some specimens collected in the course of the field work will indicate the mineralogical contents of the pegmatites. The pegmatite (34/241, 16204) accompanying the granite in the vicinity of Moras (sheet 119) shows graphic intergrowths of microcline and quartz, a little apatite, iron-ore and also some tourmaline. Tourmaline is not scarce in the Sirohi pegmatites, but it cannot be called common. It is found in all parts of the State. Thus it occurs with felspar quartz and muscovite (16215) at Nawawas (sheet 119); with the same minerals (17043) at Balda (sheet 95); at Dantrai (21091; sheet 96); etc. The Balda occurrence is interesting as 'greisening' of the intruded micaschists has occurred. The pegmatite here is composed of quartz, then a 'rim' of white muscovitic greisen (17043), and finally a 'rim' of tourmaline with quartz, the tourmaline being riddled with inclusions of quartz (17044).

Tourmaline.

A specimen (34/245, 16208) from the hills east of Moras is composed chiefly of orthoclase, with quartz and muscovite. Large books of mica do not occur in Sirohi; the muscovite found is usually quite small in size and not abundant as, *e.g.*, two miles east of Sabela (sheet 118).[1] Biotite has been noted, but it is rarer than muscovite. Muscovite occurs graphically intergrown with quartz in a small outcrop (36/92, 17072) half a mile north-west of Danta (sheet 95). This doubtfully contains fluorite. Fluorite has been noted before in a small vein, pegmatitic in nature, in slickensided Erinpura granite (42/279, 21187) from Siloi (sheet 95).

Muscovite.

Iron-ore is an infrequent constituent of the Erinpura-granite pegmatites. A specimen (42/301, 21210) from near Sindret (sheet 95) contains iron-ore as bundles of needles 'graphically' intergrown with quartz. This pegmatite is intrusive into the Sindret conglomerate. On the other side of the Abu, half a mile north-west of Kera, a pink pegmatitic rock (17138) shows abundant iron-ore. The neighbouring granite (36/161, 17139) shows abundant biotite.

Iron-ore.

[1] *Rec. Geol. Surv. Ind.*, LIX, p. 49, (1927).

The basal members of the Aravallis near Sirohi frequently show abundant epidote, which is partly derived from the alteration of the ferromagnesian minerals in the accompanying basic rocks. Part however of this epidote appears to be derived from the pegmatite of the Erinpura granite, quartz-epidote-rocks being common.

Epidote.

In the description of the Mandwara and Chandrawati brecciated quartzites (*see* p. 35), it was noted that part of the silica was derived from differentiation products of the Erinpura granite. Crushed pegmatites are not uncommon in Sirohi. Besides these two examples, they were noted in the following places :—one mile south of Kui (sheet 97) where the rock (36/796, 17604) is composed of mostly of quartz, with a little microcline; half a mile east of Khan (42/189, 21080; sheet 96) epidote being present; and 2¼ miles S. S. E. and two miles S. S. W. of Sanpura (sheet 95).

Brecciated pegmatites.

The areas in which injection rocks are common have already been indicated in the descriptions of the Aravalli and Delhi rocks. The thin veins of pegmatitic material, usually fractions of an inch in thickness but sometimes attaining a larger size, have been intruded upon a gigantic scale. It is considered that the roof of the intrusive magma was but a short distance beneath these injection types; the acidic differentiation products of the magma concentrating at its top, penetrated along the foliation or bedding planes of the superincumbent rocks.

Injected pegmatite.

Quartzites and calcic and amphibolitic rocks are relatively free from pegmatite, but exceptions occur. In general, however, it is the shales, phyllites and schists and, of course, the Erinpura granite, which are characterised by pegmatite intrusions. The following brief resumé gives the chief pegmatite occurrences on each of the one-inch sheets :—

List of chief occurrences of pegmatite.

Sheet 76.—South-eastern corner (injection types).

Sheet 77.—North-eastern corner (injection types).

Sheet 94.—Bureri; south-eastern corner.

Sheet 95.—Kalbari; Balda; Sonwara; Virapura (three-quarters of a mile long); south-east of Siloi; north-east of Dodia; Amla; north of Kankodara; west of Poidara; south and north of Akona; north of Amlari.

Sheet 96.—East of Dhanari; north-west of Watera; north-west and west of Bhimana (abundant); north of Dhauli; Thal ($1\frac{1}{4}$ miles long); east of Dhauli; north-east of Reodhar; west and south of Dadera; Bhatana; Raonakwara; Bhomra; also injection occurrences listed on page 27.

Sheet 97.—South and south-west of Abu Road; north-western corner; Bhamoria.

Sheet 117.—Kola; hill station 1,096 feet; south-western corner.

Sheet 118.—Garia; Kalumbri; frontier with Udaipur.

Sheet 119.—Kodarla; frontier with Udaipur.

Mechanics of Intrusion of the Abu Batholith.

Previously mentioned scarcity of pegmatite.

The formation of the Abu *massif* of Erinpura granite is a matter of considerable interest. The scarcity of pegmatite on its surface has already been noted and it has been stated that on the top of Mount Abu, one seems to be much further from the roof of the batholith than if one were on the plains some 3,100 feet lower in elevation. The remarkable parallelism of the boundaries of the Abu *massif* has also been noted.

First stages of intrusion.

It is considered that the Erinpura granite now forming the Abu *massif* was intruded in the form of a gigantic plug or batholith more or less at or under the junction of the Aravallis and Delhis and that the superincumbent Aravalli and Delhi rocks were 'domed' above it as the intrusion progressed (see p. 77). The magma also quietly stoped its way through these rocks, huge blocks of the ancient rocks sinking into it and possibly being assimilated

The first stages of the intrusion are depicted diagrammatically in Figure 4.

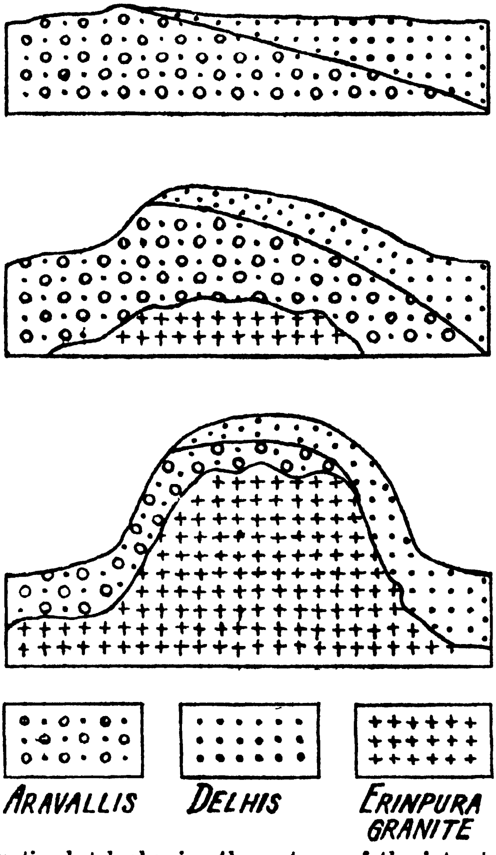

FIG. 4.—Diagrammatic sketch showing three stages of the intrusion of the Erinpura granite, at present forming Mount Abu, into the Aravalli and Delhi rocks at and near their junction.

Relief of pressure by lateral faulting.

The strain caused by the intruding magma was great and the pressure was relieved most probably by a series of faults on either side, north-western and south-eastern. There was, however, no sudden giving way of the superincumbent rocks above the margins of the intrusive magma. The relief was gradual, and the intruding magma again took advantage of the relief of pressure against its intrusion by advancing gradually still further in its upward journey. At last, however, equilibrium was established and the magma cooled under conditions which allowed of extremely slow

crystallisation with the consequent formation of a coarse-grained rock. The upper part of Figure 5 represents diagrammatically the conditions at this time. The magma was covered by a thick mantle of Delhi and Aravalli rocks which successfully resisted the magma, still subjected to considerable pressure. The effect of this pressure, which persisted throughout the cooling process, is evidenced in the gneissic foliation so common in the Erinpura granite forming the Abu *massif*.

Weathering.

Atmospheric agents commenced their never-ceasing work of destruction and slowly but surely the blanket of rocks covering the granite was removed and the granite itself attacked. Present day conditions are represented diagrammatically in the lower part of Figure 5.

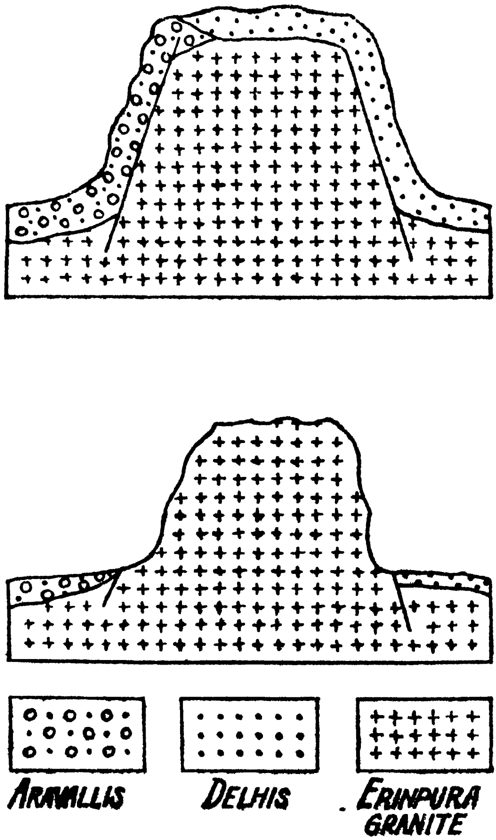

FIG. 5.—Diagrammatic sketch showing (above) the conditions at the time of crystallization of the Erinpura granite forming Mount Abu; and (below) Mount Abu as it is at present.

Mention has already been made of the sill-like nature of the intrusive mass of Erinpura granite forming the Bhamoria outcrop.

Sills of granite.

The Gorsa outcrop has also been alluded to as a sill-like sheet of Erinpura granite. A study of its relations shown in figure 1 of Plate 11 will demonstrate the probability of its having been intruded along the bedding planes of the calcic rocks in this neighbourhood during the movements responsible for the folding of the Ajabgarh rocks. A certain amount of shearing must have accompanied the intrusion as there is evidence of faulting near the western limb of the Gorsa outcrop.

Reference may conveniently be made here to Mr. J. B. Auden's work on the Erinpura granite exposures in the contiguous areas

J. B. Auden.

of Udaipur State. This is summarised in the General Report for 1930.[1] The 340°-160° system of jointing noted by Mr. Auden in the Erinpura granite is not conspicuously developed in any of the Sirohi exposures, where jointing, though common, does not as a rule possess any definite direction, except in the Waloria-Bhamoria outcrops where the major joints are parallel to and at right angles to the general N. N. E. S. S. W. strike of the Delhis.

It may also be mentioned that from his field work on the Jodhpur-Udaipur frontier, Dr. A. M. Heron has recognized two

A. M. Heron.

types of intrusive forms of Erinpura granite, 'sheet complexes' and 'massive stocks', which grade into each other both in time, in form, and in place.[2] He considers the former to be possibly slightly older than the latter, being

'injected during the active folding movements, but towards their end, while the bosses arose somewhat later, under more quiescent conditions. The process however must have been a continuous one, and there is no reason to believe that in different parts of the (Aravalli) range, it or its events happened at the same actual time or at the same relative stage in the history of the diastrophism. The "sheet complex" type of intrusion consists of innumerable parallel sheets of aplite, sheared and imperfectly crystallised pegmatite, and granite, the last being both coarse and fine in grain, both porphyritic and even-grained, and both foliated and homogeneous.

'The "massive stock" type of intrusion is the normal one usually assumed by granite. Topographically it may give rise to high, bold hills of bare rock, with exfoliating domes and tors, or may just protrude from the alluvium as innumer-

[1] *Rec. Geol. Surv. Ind.*, LXV, pp. 137-139, (1931).
[2] Unpublished Mss. kindly shown to the author.

able low turtlebacks and gently convex tables. The stock intrusions perhaps lift the strata upwards. In the exceptional cases where they are gently inclined, a laccolite is formed, as is exemplified by the Ana Sagar mass near Ajmer. With the much more usual highly dipping or vertical strata, blocks of the roof are, we may suppose, pushed upwards along planes of weakness provided by the highly inclined bedding.'

CHAPTER VII.

BASIC ROCKS, POST-ERINPURA-GRANITE BUT PRE-MALANI IN AGE.

Introductory Discussion.

It is proposed to discuss in this chapter those basic rocks which are later in age than the Erinpura granite, but which were intruded into it, or into Aravalli or Delhi rocks, before the Malani period. These belong to the third basic phase mentioned in Chapter II. Those intruded after the Malani period are discussed in Chapter XI.

Age.

The metamorphic imprint which the rocks of Sirohi bear was gained, for the greatest part, at the close of the Delhi period when the N. N. E.–S. S. W. trending foliation was imposed on them. Most of the folding antedated the intrusion of the Erinpura granite. Accordingly the basic rocks now discussed have not suffered such severe metamorphism as those intruded before the close of the Delhi period (*i.e.*, the Aravalli contemporaneous basic rocks and the Delhi basic rocks). Hornblende- and actinolite-schists and amphibolites are absent. The usual hypabyssal forms found are best described merely as altered basalts or altered dolerites, or, where metamorphosing agencies have been more severe, epidiorites. The plutonic forms, gabbros, picrites, sodalite-syenites, etc., have been noted in three localities only. These will be described first.

Metamorphic imprint of Sirohi rocks.

Kinds of rocks found.

Kui and Chandrawati Gabbros and Dolerites.

Mention has been made in the description of the Delhi rocks of the occurrence of two exposures of gabbro in the southern part of the State. The most northerly of these lies half a mile north-east of the small scattered village of Kui (sheet 97); it is half a mile in extent from north to south and a quarter of a mile wide. The second outcrop lies half a mile east of Chandrawati (sheet 97) and is double the size of the former. Characteristically the gabbro weathers spheroidally, with a pitted surface.

Localities.

An analysis by Mons. F. Raoult of the olivine-gabbro (36/789, 17596) from one mile east of Chandrawati is as follows, that of an olivine-gabbro from Wallbach, Hesse,[1] and of a troctolite from Coverack, Cornwall,[2] being given for purposes of comparison:—

Analysis of olivine-gabbro.

TABLE III.

	36/789.	A.	B.
	Per cent.	Per cent.	Per cent.
SiO_2	47·02	47·78	45·73
TiO_2	0·36	0·26	..
Al_2O_3	20·24	20·51	22·10
Fe_2O_3	1·25	2·54	0·71
FeO	6·34	6·07	3·51
MnO	0·12	..	..
MgO	9·56	4·62	11·46
CaO	10·54	10·65	9·26
Na_2O	2·32	4·69	2·54
K_2O	0·47	0·51	0·34
H_2O —105°C	0·11	0·64	4·38
H_2O +105°C	1·05		
CO_2	0·73	..	..
P_2O_5	..	0·49	..
Other constituents	..	0·31	..
TOTALS	100·11	99·07	100·03
Specific gravity	2·904	..	..

36/789. Olivine-gabbro, one mile east of Chandrawati (sheet 97), Sirohi State (F. Raoult).

A. Olivine-gabbro, Wallbach, Hesse (Sonne).

B. Troctolite, Coverack, Cornwall.

[1] J. P. Iddings, 'Igneous Rocks', London, II, p. 216, (1913).
[2] F. T. S. Houghton, *Geol. Mag.*, VI, p. 504, (1879).

A study of these figures shows that the analysis of the Chandrawati specimen bears a relationship to that of an olivine-gabbro and also that of a troctolite. The magnesia content (9·56) of 36/789 is more than that of the olivine-gabbro (4·62) but less than that (11·46) of the troctolite. From these and other considerations, the Chandrawati rock is intermediate in nature between an olivine-gabbro and a troctolite.

Conclusions from analysis.

Felspars.

The section (17596) of the rock analysed (36/789) shows olivine altering to serpentine, augite, a little biotite and iron-ore and abundant felspar. Determination on the Federov stage of the composition of two individual felspars forming a Carlsbad twin gave a result of 60 per cent. An, one being slightly more basic than the other. Both individuals contain albite lamellæ and the more basic also contains a pericline lath; the composition of those is indeterminate. Another specimen from the same locality (36/788, 17398) contains slightly more basic felspars. The compositions of two individuals forming albite twins (with subordinate pericline twinning) were determined as 70 and 73 per cent. An respectively.[1] Two other individuals in the same section, twinned according to the pericline law, with subordinate albite twinning, have a composition of 65 per cent. An. This specimen (36/788) has a specific gravity of 2·86. Similar results were obtained for the felspars in a third specimen (36/792, 17599). The compositions of two individuals in a Carlsbad twinning combination (with albite and pericline lamellæ) were measured. One has a composition of 69 per cent. An. The other is zoned, having compositions of 77 and 69 per cent. An. The compositions of three individuals forming Ala A and Carlsbad twins in the same section differ, being respectively 68, 70 and 75 per cent. An.[2] The above results are summarised in Table IV below.

TABLE IV.

Section.	Anorthite percentage of individuals. I.	II.	III.
17596	60	60	..
17398	70	73	..
	65	65	..
17599	69	69 and 77	..
	68	70	75

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 167, (1931).
[2] For detailed descriptions of these combinations in slide 17599, *see* A. L. Coulson, *ibid.*, pp. 168-169, (1931).

The mean composition of the above eleven individuals is 68 per cent. An.

Unavailing efforts were made to isolate fragments of the augite occurring in the above specimens of olivine-gabbro in order to determine its refractive index for comparison with the titaniferous augite found in the contact metamorphic products of the gabbro with calcic rocks.[1] It is certain, however, that the titanium content of the augite of the gabbro is very much less than that of the augite in the endomorphic rock. This is borne out by the small percentage of titania (0·36) in the analysis of 36/789. Augite is not very abundant in the gabbro; indeed, as stated above, the rock is at times best called a troctolite, being frequently composed of plagioclase and olivine with little or no augite.

Augite.

Biotite is a common though not abundant constituent of the gabbro; its pleochroism is as follows:—

Biotite.

$\mathfrak{a}$=light yellow,
$\mathfrak{b}$=dark brown,
$\mathfrak{c}$=dark brown.
Absorption :—$\mathfrak{c}=\mathfrak{b} > \mathfrak{a}$

It is more common in the doleritic types than the gabbroitic.

The gabbro grades into doleritic forms which are very common in the neighbourhood of Bhainsasing (sheet 97). There is little doubt that these dolerites, which vary greatly in texture, are the hypabyssal equivalents of the gabbro. They contain felspars of the same composition. Thus determination by Federov methods of the composition of two individuals in a biotite-dolerite from Bhainsasing (17594), which form a Carlsbad twin, gave a result of 65 per cent. An. One individual contains albite lamellæ.

Dolerites.

There is no conclusive evidence regarding the age of these gabbros and dolerites. They are definitely post-Delhi and almost certainly post-Erinpura-granite in age as they are not intruded or altered by this granite and its pegmatites. There are no Malani rocks in their neighbourhood and the question whether or not they are pre-Malani must remain undecided. They have been considered as pre-Malani by reason of the fact that dolerites in the western part of the State, which bear strong resemblances to them, are post-Erinpura-granite but pre-

Age uncertain.

[1] A full description of the optical properties of the titaniferous augite is given in the author's paper in *Rec. Geol. Surv. Ind.*, LXIII, pp. 448-450, (1930).

Malani in age, being intruded by the Malani dykes and granites. It must be understood, however, that this correlation with the pre-Malani basic rocks is entirely presumptive; the same remarks are equally applicable to the Mundwara suite of igneous rocks which will now be described in detail.

Mundwara Suite of Igneous Rocks.

The rocks forming the Mundwara suite of igneous rocks constitute a very interesting series. They crop out in Erinpura granite to the west and north-west of the village of Mundwara (sheet 95) at a distance of some two to three miles from the western border of the State with Jodhpur. The large village of Jaswantpura in Jodhpur lies 5½ miles to the south-west.

Locality.

Sketch map.

The distribution of the rocks forming the suite may be gathered from a study of Figure 6.

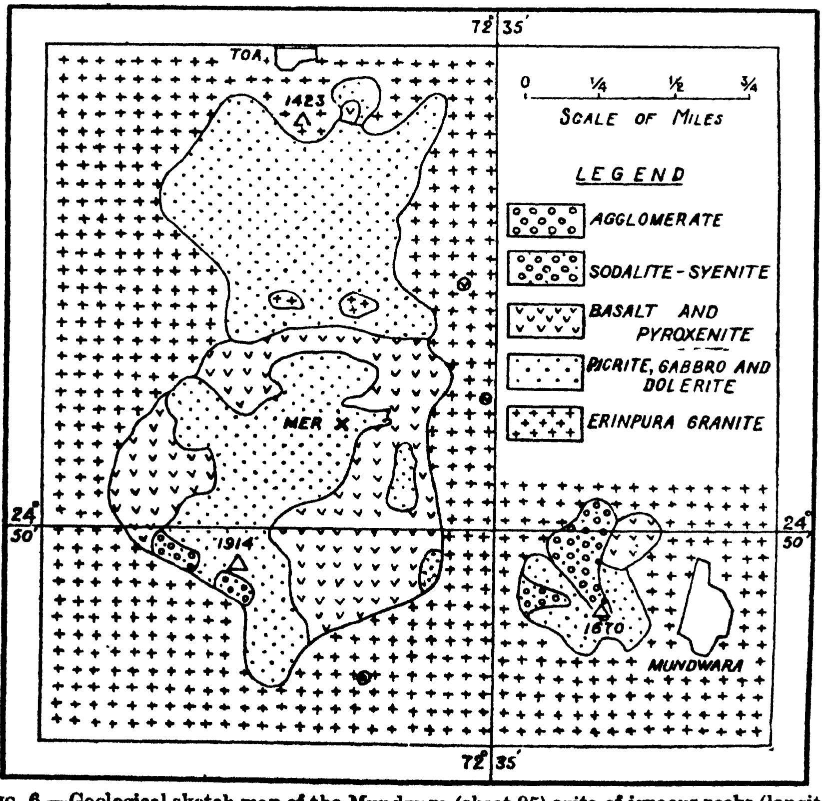

FIG. 6.—Geological sketch map of the Mundwara (sheet 95) suite of igneous rocks (longitude of the one-inch sheet).

There are two chief outcrops. The first constitutes hill station 1,670 feet, an almost circular hill at the eastern foot of which lies the village of Mundwara. The hill rises precipitously from the plains. The second outcrop forms the remarkable circular ridge of hills (Plate 6, fig. 1) encircling the deserted village of Mer, the inhabitants of which in ancient times migrated out of the hills to found the village of Mundwara; this 'ring' is also connected with the smaller but similar 'ring' of hills immediately south of Toa. These rings have great physiographical interest, but it is proposed to postpone the question of their origin until the rocks constituting them have been described. Hill station 1,914 feet forms the highest peak of the Mer ring; hill station 1,423 feet is the highest point of the Toa ring. The general level of the surrounding country is about 950 feet above sea-level.

Distribution.

A variety of rocks is found in both outcrops. The fundamental magma appears to have been very basic, somewhat equivalent to a picrite in composition. Coarsely crystalline rocks, composed of olivine, augite, magnetite and subordinate felspar occur in the centres of the Toa and Mer rings. At times the felspar is merely interstitial, very subordinate in quantity, and the rock (42/243, 21147) is best described as a picrite (specific gravity, 3·25). Other varieties (42/244, 21148) are intermediate between an olivine-gabbro and a picrite (specific gravity, 3·19). Again, sufficient felspar may be present to warrant the rock (42/245, 21149) being termed an olivine-gabbro (specific gravity, 3·23). The augite of these rocks is commonly twinned and zoned; it is slightly titaniferous. Biotite occurs in the last two rocks.

Gradation from picrite to olivine-gabbro.

These types grade insensibly into doleritic forms, less coarse in texture. Thus the major part of the Toa and Mer rings is composed of doleritic rocks of very variable nature. A specimen (42/235, 21138) from the summit of hill station 1,914 feet contains abundant biotite and laths of plagioclase felspar, with lesser quantities of titaniferous augite and iron-ore, the rock being a biotite-dolerite (specific gravity, 2·94). A second specimen (21140) from the Mer ring, three-quarters of a mile north-east of the hill station above, is more basic, containing olivine. This olivine-dolerite also possesses large prisms of apatite and its augite is very titaniferous. Similar strongly pleochroic

Dolerite.

titaniferous augite was noted in another olivine-dolerite (42/238, 21142) from near the same locality (specific gravity, 3·07). In a fourth specimen (42/242, 21146; specific gravity, 2·98), from one mile west of Mundwara, augite and biotite are largely intergrown, the felspar being without crystal boundaries and crowded with minute inclusions.

The rings appear to have been 'breached' in several places, basaltic rocks being formed. These predominate on the north-eastern flanks of hill station 1,914 feet, stretching from here between the Toa and Mer rings. They occur again on the western side of the Mer ring. These basaltic types merge into doleritic rocks. Thus a specimen (42/236, 21139; specific gravity, 3·19) from three-quarters of a mile north of hill station 1,914 feet, may be considered as intermediate in character between an olivine-basalt and an olivine-dolerite. It contains basaltic hornblende, olivine, augite, biotite, iron-ore and plagioclase. It is holocrystalline but generally fine-grained, the biotite being intergrown with augite, felspathic material and iron-ore. Hypidiomorphic crystals of hornblende, augite and olivine and plagioclase laths occur surrounded by a granular aggregate of pyroxene. The section shows a Baveno plagioclase twin.

Basalt.

A typical hornblende-basalt (42/232, 21134; specific gravity, 2·74) which occurs in the Mer ring half a mile north-west of hill station 1,670 feet, contains abundant large crystals of strongly pleochroic basaltic hornblende, prisms of apatite and irregular masses of iron-ore, with subordinate biotite and augite, set in an extremely fine-grained, felted and glassy matrix of felspar and other minerals. The pleochroism of the hornblende is:—

Hornblende-basalt.

$\mathfrak{a}$=honey-yellow,
$\mathfrak{b}$=dark brown,
$\mathfrak{c}$=dark brown.

Absorption:— $\mathfrak{c} \geqq \mathfrak{b} > \mathfrak{a}$

Different basaltic types were noted on the north-eastern flank of hill station 1,670 feet. A specimen (42/241, 21145), of specific gravity 3·01, contains a large compound crystal of augite composed of numerous simply twinned augite individuals intergrown with iron-ore and a fine-grained ? micaceous mineral; together with laths of plagioclase of greater or lesser magnitude, iron-ore, small augites and a black glass. The rock is distinctly fragmentary in texture.

The same gradation from dolerites to basalts was noted in a small intrusion one mile S. S. E. of Marri, isolated from the Toa and Mer rings and hill station 1,670 feet. A doleritic type (21150) consists of abundant olivine, titaniferous augite, biotite, iron-ore and plagioclase laths; a basaltic type (21151), into which the former grades, is composed of fine plagioclase laths accompanying a fine-grained mass of augite and iron-ore, with little prisms of basaltic hornblende and a fair quantity of secondary calcite.

Gradation from dolerite to basalt.

Similarly the basaltic rocks grade into pyroxenitic types. Thus a specimen (21137) from the E. N. E. flank of hill station 1,914 feet, basaltic in character, consists of abundant phenocrysts of augite, very slightly titaniferous, with iron-ore, basaltic hornblende, olivine, biotite and plagioclase, set in a microcrystalline groundmass of the same minerals. This rock is fragmentary in texture. It grades into a very basic type, consisting chiefly of titaniferous pyroxene with subordinate iron-ore and a little biotite (42/233, 21136). It has the very high specific gravity of 3·47. An intermediate type (42/237, 21141), approaching a pyroxenite but much finer-grained and containing occasional large prisms of basaltic hornblende, biotite, iron-ore, and a fair quantity of interstitial felspar in addition to abundant augite, possesses the lower specific gravity of 3·21. One large crystal of augite in this slide is conspicuously zoned, the inner portion being definitely titaniferous and sharply delimited from the outer normal type; the whole of the crystal extinguishes between crossed nicols at the same time.

Gradation from basalt to pyroxenite.

All the above-described rock types found in the Mer and Toa rings, comprising picrites, olivine-gabbros, olivine-dolerites, biotite-dolerites, hornblende-basalts, augite-basalts, olivine-basalts, pyroxenites, etc., grade into one another. There are few 'mappable' junctions between them. It was found convenient in the field to map basaltic and pyroxenitic rocks together and picritic, gabbroitic and doleritic forms as one. The separate mapping of the numerous petrological varieties found in this area would entail, were the work done thoroughly, at least a whole field season. It was impossible for the author to spend that time in one small area, crowded though it was with scientific interest.

Varieties mapped.

It will have been noted that sodalite-rocks have been mapped as occurring on the south-western flanks of the Mer ring and to a greater extent on the northern and western flanks of the isolated hill 1,670 feet. A specimen (42/240, 21144; specific gravity, 2·80), from just west of hill station 1,914 feet, consists of abundant orthoclase and anorthoclase, the latter in large crystals, with a fair quantity of sodalite, the ferromagnesian minerals being biotite and aegirine-augite. Iron-ore and large prisms of apatite are accessories. The sodalite generally does not possess crystal boundaries and contains numerous fluid and other inclusions. It has no cleavage but shows a fair number of fracture cracks. It does not show anomalous double refraction. It is light pink to flesh-coloured in the hand specimen and colourless in thin section. No nepheline is visible in the slide.

Sodalite-syenites of the Mer ring.

These sodalite-syenites occur in two outcrops on the outer flanks of the Mer ring, the characteristic type being as coarse-grained as the above-described example. There are, however, finer-grained varieties which merge insensibly into the coarser. The locality of these occurrences is extremely precipitous and as the area is covered by loose blocks, the boundaries are only approximate; it is impossible to make out the relationship between the alkaline rocks and the doleritic types of the ring proper.

On the northern and western flanks of hill station 1,670 feet, the evidence, though not conclusive, is a little more definite. This hill rises steeply from the plains and though the bottom regions are covered with doleritic blocks, the actual junction of these with the Erinpura granite which they intrude is very far up the hill on its southern and eastern sides. The basaltic rocks occurring on the north-eastern flanks of the hill have been described above (*see* p. 85). If one encircles the hill from these basaltic rocks in a counterclockwise direction, one meets sodalite-syenites, then dolerites, again a small mass of sodalite-syenite, and then more dolerites which continue to the basalts already mentioned.

Sodalite-syenites of hill station 1,670 feet.

A specimen (42/65, 21135) of the first met sodalite-rocks, which form the northern flanks of the hill, possesses a specific gravity of 2·75 and contains the same minerals as noted above for the Mer specimen (42/240, 21144). The rock has abundant large masses of sodalite of refractive index 1·485$\pm$0·001, generally allotriomorphic but occasionally hypidiomorphic. A few crystals of nepheline, uniaxial and negative, are present in one section. A small amount of analcite probably occurs.

Analysed specimen.

Sphene is an accessory. As previously, the augite varies in colour, the marginal portions as a rule being distinctly greener and more pleochroic than the central parts and extinguishing differently between crossed nicols; they resemble aegirine-augite.

Analyses.

An analysis by Mons. F. Raoult of this specimen (42/65) is given in Table V, other analyses of alkaline rocks being appended for comparison:—

TABLE V.

	42/65.	A.	B.	C.	D.
	Per cent.	Per cent.		Per cent.	Per cent.
SiO_2	49·88	56·45	54·92	49·38	53·53
TiO_2	2·54	0·29	..	0·63	0·44
Al_2O_3	17·95	20·08	24·05	17·31	19·69
Fe_2O_3	2·42	1·31	5·67	4·20	5·09
FeO	5·33	4·39	..	5·25	2·83
MnO	0·24	0·09	..	0·08	0·24
MgO	2·37	0·63	0·75	0·53	..
CaO	4·14	2·14	1·45	2·23	1·87
Na_2O	8·47	5·61	9·54	13·87	9·61
K_2O	4·55	7·13	3·05	2·55	5·23
H_2O—105° C	0·07	0·26[1]	..	1·46	0·59
H_2O+105° C	0·73	1·51[2]	..		
CO_2	..	..	..	..	0·40
P_2O_5	1·24	0·13	..	..	0·31
Cl	..	0·43	0·82	1·68	..
Other constituents	..	..	..	0·61	0·04
TOTALS	99·93	100·45	100·25	99·78	99·87
Less O = Cl	..	0·10	0·18	0·37	..
TOTALS	99·93	100·35	100·07	99·41	99·87
Specific gravity	2·770	..	..	..	..

42/65. Sodalite-syenite, half-way up the northern slopes of hill station 1,670 feet, west of Mundwara (sheet 95), Sirohi State, Rajputana (F. Raoult).

A. Sodalite-syenite, Square Butte, Highwood Mountains, Montana, U. S. A. (W. H. Melville).[3]

B. Mean of two analyses by B. C. Gupta of the elæolite-syenite of Kishengarh, Rajputana.[4]

C. Sodalite-foyaite, Tupersuatsiak, Greenland (Winther).[5]

D. Foyaite, Korok, South Greenland (Winther).

[1] —100° C.
[2] +100° C.
[3] *Amer. Journ. Sci.*, XLV, p. 296, (1893).
[4] Analyses given by A. M. Heron, *Rec. Geol. Surv. Ind.*, LVI, p. 186, (1926).
[5] J. P. Iddings, 'Igneous Rocks', London, II, pp. 279-280, (1913).

The above analyses will be discussed later (*see* pp. 90–91).

Other specimens.

A specimen (42/230, 21132; specific gravity, 2·57) from half-way up the hill, not far distant from the analysed specimen, is finer-grained than it and contains more sphene and little biotite, the pyroxene resembling the variety described before. Also prisms of hornblende are present with pleochroism :—

$\mathfrak{a}$=light brownish green to light green,

$\mathfrak{b}$=dark brownish green,

$\mathfrak{c}$=dark brownish green to dark green.

Absorption :— $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

These plutonic types grade into hypabyssal rocks, sölvsbergitic in nature. Thus a specimen (42/229, 21131; specific gravity, 2·75) from low down on the northern side of the hill, contains no definite nepheline but small isotropic masses of ? sodalite and abundant felspathic material in the form of laths and interstitial masses, all with undulose extinction (? anorthoclase). The pyroxene possesses a distinct violet tint, is positive, and has a small optic axial angle (21128). Similar varieties were met on the actual summit of the hill. One specimen (42/225, 21127) has a specific gravity of 2·69; an adjacent rock (42/226, 21128) possesses a specific gravity of 2·70.

Vein with ægirine.

The exact relationship between the dolerites and these alkaline rocks is not clear. A vein (42/231, 21133), apparently intruding the dolerite half-way up the hill on the north-western side, consists of orthoclase and anorthoclase with a little plagioclase and ægirine of pleochroism :—

$\mathfrak{a}$=deep grass-green,

$\mathfrak{b}$=grass-green,

$\mathfrak{c}$=brownish green.

Absorption :—$\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$

$\mathfrak{a} : c < 3°$

Dolerite of hill station 1,670 feet.

The dolerites resemble those of the Mer and Toa rings. A specimen (42/228, 21130; specific gravity, 3·00) from half-way up on the northern side of the hill, and another (42/227, 21129; specific gravity, 2·93) from almost at the top of the hill, contain titan-

iferous augite very similar to that noted in the hypabyssal varieties of alkaline rocks (21127; 21128; and 21131) but more titaniferous; it is likewise positive and has a small optic axial angle.

Dolerites related to the alkaline rocks.

The presence of this titaniferous augite in the hypabyssal alkaline rocks and in the neighbouring dolerites suggests that they are genetically related. The occurrence of a dyke with ægirine apparently cutting the dolerites would indicate that the alkaline rocks are the younger, but it is thought that this difference in age is of no great magnitude and that the alkaline rocks and the other rocks of the Mundwara suite were derived from the same magma by a process of differentiation.

Conclusions from analysis of sodalite-syenite.

A study of the figures in Table V (p. 88) shows that there is considerable difference in composition between the sodic rocks of Mundwara, Sirohi State, and those from Kishengarh, the only other occurrence in Rajputana with the exception of the specimen (13/803) described by Holland but collected by La Touche from Sarnu in Jodhpur.[1] It is unfortunate that there is no analysis of the Sarnu specimen as the thin section (9162) bears a certain resemblance to the Mundwara hypabyssal varieties. It is stated by La Touche[2] to be possibly intrusive into the ? Cretaceous Barmer sandstone and so is possibly much younger than the age tentatively ascribed to the Mundwara rocks by the author. Dr. Heron's Kishengarh rocks are probably pre-Delhi in age[3] and thus are much older than either the Sarnu or Mundwara specimens. Other alkaline rocks have been recorded in India from Sivamalai,[4] Vizagapatam,[5] Mount Girnar, Kathiawar,[6] and Mogok, Upper Burma,[7] but such analyses of these rocks as are available do not show similarity to the Mundwara specimen (42/65). A closer resemblance, however, may be noted with the sodalite-foyaite from Tupersuatsiak and the foyaite from Korok, both in Greenland. The proportion of soda to potash in the Tupersuatsiak analysis is very different from that in the Mundwara analysis, but silica, alumina,

[1] *Mem. Geol. Surv. Ind.*, XXXV, pp. 92-93, (1902).
[2] *Op. cit.*, pp. 75, 92.
[3] *Rec. Geol. Surv. Ind.*, LVI, p. 180, (1926).
[4] *Mem. Geol. Surv. Ind.*, XXX, pp. 169-217, (1901).
[5] *Gen. Rept. Geol. Surv. Ind.*, 1902-03, p. 25, (1903). *Rec. Geol. Surv. Ind.*, XXXVI, pp. 19-22, (1907).
[6] *Q. J. G. S.*, LVII, pp. 38-54, (1901).
[7] *Rec. Geol. Surv. Ind.*, LXVI, pp. 94-95, (1932).

iron oxides and lime show similarities. The soda-potash proportions in the Korok specimen are more akin to the Mundwara ratio but the silica and alumina percentages are both a little higher. There is but little resemblance between the sodalite-syenite of Square Butte and the Mundwara specimen, but the analysis of the former has been inserted as analyses of such rocks are rare. It is unfortunate that the present financial stringency precludes the acquirement of a complete set of analyses of the chief types found in this interesting area.

Ring-dykes and cone-sheets.

The ring-dykes of Mull,[1] Slieve Gullion,[2] Arran,[3] Ardnamurchan,[4] etc. are now well known and it is a matter of no little interest to find a somewhat parallel occurrence in Rajputana. The mechanics of formation of these ring-dykes and of cone-sheets have been discussed by various authors.[5] The following abstracts from H. H. Thomas' notes[6] succintly summarises the present views :—

'Cone-sheets are important features in Skye, Rum, Mull, Ardnamurchan, and Carlingford, and are clearly connected with the plutonic centres of these regions where there is evidence to show a relation between ring-dyke and cone-sheet intrusion. The idea of development of cupolas on the main magma basin seems necessary to explain the origin of cone-sheets and ring-dykes. Such cupolas are assumed to be steep dome-like or paraboloidal upward extensions of the main magma-reservoir into relatively cool regions of the crust. From the nature of cone-sheets it is practically certain that their formation is due to an excess of magmatic pressure acting vertically upwards upon a relatively thin crustal covering, in a successful attempt on the part of the magma to raise its roof. ————

' The uplift of the roof, with attendant doming of the central area above the magma-reservoir, must in every case of abundant sheet injection have been of the order of thousands of feet. ———As it appears that cone-sheet injection is dependent upon locally applied magmatic pressure there is no reason why such should not occur, or recur, whenever the magmatic pressure within the reservoir was sufficient to overcome the downward pressure of the crust. Such excessive magmatic pressure, accompanied by the intrusion of cone-sheets, was developed at more than one period and at more than one centre both in Mull and Ardnamurchan. ————

' The conception of ring-dyke intrusion was the result of work carried out by Messrs. Clough, Maufe, and Bailey on the cauldron subsidence of Glencoe. They

[1] 'The Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban', *Mem. Geol. Surv. Scot.*, pp. 340-341, (1924).

[2] J. E. Richey, *Rep. Brit. Ass.* for 1928, pp. 544-545, (1929).

[3] 'The Geology of Arran', *Mem. Geol. Surv. Scot.*, p. 169, (1928).

[4] 'The Geology of Ardnamurchan, North-West Mull and Coll', *Mem. Geol. Surv. Scot.*, pp. 201-342, (1930).

[5] 'The Geology of Ardnamurchan', pp. 56-59, 69-78. 'The Tertiary and Post-Tertiary Geology of Mull', *loc. cit.* 'The Geology of Ben Nevis and Glen Coe', *Mem. Geol. Surv. Scot.*, LIII, pp. 125-127, (1916).

[6] 'The Geology of Ardnamurchan', pp. 56-59.

found that outside a circular fault, which bounded an area of subsidence, plutonic rocks had been intruded in annular form, and to these intrusions the name ring-dyke was eventually applied on account of their vertical or almost vertical junctions.

'The general theory of subsidence, as originally enunciated for Glencoe, appears to be the only one that explains the observed facts, and therefore it is assumed that most of the plutonic rocks of the British Tertiary Centres have risen in their respective positions as the result of the subsidence into a magma-reservoir of a steep-sided conical crustal block. Such subsidence would cause the welling up of the magma into the fissure that bounds the subsiding mass, and, if the ring-fracture reached the surface, a central type of lava eruption would be likely to ensue, as in the case of the South-east Caldera of Mull. If, however, the subsiding block was detached from the under part of the solid crust, the fractures would not of necessity reach the surface and the space formed over the subsiding mass would be filled with magma that would be continuous with the lateral steep-sided ring-dyke intrusion, but be more or less horizontal in disposition. ——

'Repeated subsidence at the same centre has often allowed further influxes of magma to fill reopened fissures, or to be injected up fresh circular fractures, with the result that we are presented with a succession of arcuate intrusions arranged about a common centre and vertical axis. ——

'It would appear, in contradistinction to cone-sheets, that the formation of ring-dyke fissures and the concurrent intrusion of magma are independent of excessive magmatic pressure but are consequent on crustal collapse.'

No reason to postulate subsidence at Mundwara.

One of the most characteristic features of the Mundwara suite of rocks is the total absence, with the exception of one dyke with ægirine, of definite junctions between the numerous varieties occurring in the area. There are two central masses of picrite, one in the Mer ring and the other in the Toa ring. The term 'ring' has been applied in a physiographical rather than a petrological sense inasmuch as a study of the sketch map forming Figure 6 does not indicate the circular nature of the hills which is brought out by figure 1 of Plate 6. The picrites change locally within short distances to olivine-gabbros and both rocks merge into doleritic forms. It is these dolerites which, being more resistant to weathering than the coarser-grained picrites and olivine-gabbros, form the 'backbones' of the hills. They can be explained as chilled marginal facies of the two bosses responsible for the Toa and Mer rocks. There seems to be no reason in these cases to postulate the detachment and subsidence of a mass from the under part of the crust (in this case, the much older Erinpura granite) and the filling of the space over the subsiding mass with magma of a more or less horizontal disposition. Nor is it thought that the formation of the Lonar Lake[1] is akin to that of the Toa and Mer rings.

[1] T. H. D. La Touche and W. A. K. Christie, *Rec. Geol. Surv. Ind.*, XLI, pp. 266-285, (1912).

The intrusion of the Toa and Mer bosses appears generally to have been quiet. An agglomeratic type (42/234) was noted on an independent but subsidiary vent, 1¼ miles W. S. W. of Mundwara. Several other subsidiary plugs were noted in the vicinity of the two rings, east and south-east of Toa. A small black plug (42/216, 21117) 1½ miles N. N. W. of Sildar, and a hornblende-porphyrite dyke (42/248, 21154), with large crystals of sphene, from half a mile W. S. W. of Jela, are undoubtedly related to the Mundwara suite. The latter rock strikes E. N. E., away from the Toa ring, from which it is distant some 2½ miles. Hill station 1,670 feet is formed of rocks due to igneous activity from a further large pipe, subsidiary, however, to the main Toa and Mer bosses. Evidence is lacking of the intrusion of any cone-sheets of lava.

Intrusion generally quiet.

Problem of the basalts.

The presence of basaltic rocks offers a problem of no little interest and there seem to be two possible theories for their occurrence.

Confining one's attention first to the Toa and Mer rings, one could possibly regard these as the sites of two volcanoes, the basic magma of which quietly stoped its way to the surface, the forces assisting its ascent to the surface at all times being strictly under control and almost in equilibrium with those preventing its ascent. A doleritic facies was developed along its contact with the intruded Erinpura granite, but the main mass of magma remained still fluid except for its surface layers. The two volcanoes remained more or less dormant until the accumulated stresses were such that slow activity again commenced, with the resultant quiet welling up of the magmatic material within the rings. This material breached the doleritic ring in several places, there being the formation of basaltic lava flows outwards from the breached places. This period of activity was short-lived and of no great extent and equilibrium being once again established, the central magma cooled extremely slowly with the resultant formation of picrites and olivine-gabbros. The subsidiary Mundwara plug is considered not to have reached the surface at the same time as the Toa and Mer volcanoes. The recrudescence of activity responsible for the welling up of the magma in these volcanoes also affected the Mundwara plug and its magma was enabled to break through the superincumbent granite in the form of the lavas now found on its flanks. The alkaline rocks of Mer and Mundwara could have been injected during the last cooling stages.

Volcanic theory.

It is not thought, however, that this is the true explanation of the presence of these basaltic rocks. The gradation of all types of rock one into the other has been emphasised throughout this description. It has also been stated that the Mundwara rocks are probably related to the extensive post-Erinpura-granite but pre-Malani dolerites and basalts which are so common in the western part of the State and, also, to the Chandrawati and Kui gabbros and associated dolerites in the south-eastern region of Sirohi. The former at least of these are definitely of great antiquity. The volcanic theory given above would entail the assumption of a relatively young age for the Mundwara rocks, as the amount of denudation from the time of their intrusion and extrusion must of necessity have been small if the basalts are considered as true lava flows; otherwise they would long since have been eroded away.

Chilled facies theory.

Accordingly it is considered that the true explanation of the occurrence of these basaltic rocks lies in the fact that they never reached the surface, but were formed as a chilled facies of the basic magma consequent upon a sudden release of pressure by partial collapse of the superincumbent Erinpura granite. Thus a condition of equilibrium is postulated to have been reached when the basic magma quietly stoped its way into the Erinpura granite, doming of the granite having taken place at the same time.

There would then be two bosses of magmatic material, possibly still fluid in their central regions. With the sudden collapse of the resistance of the Erinpura granite due to fracture consequent upon accumulated stress, the still fluid material (or if solid or semi-solid, it would liquefy with release of pressure) would break through the doleritic material forming the marginal ring. Equilibrium was quickly reestablished, the escaped material soon cooling on meeting relatively cool rocks and congealing the outlets.

The state of equilibrium then persisted and the central material was enabled to cool under conditions permitting the slow crystallisation of minerals, giving picrites and olivine-gabbros. Before complete solidification, however, a fresh release of pressure took place and the alkaline differentiation product of the cooling magma was intruded in the form of a magma which, on itself cooling slowly, gave rise to the sodalite-syenites and other alkaline rocks found on the outer south-western flanks of the Mer ring and on parts of the Mundwara plug.

Basalts, Dolerites and Epidiorites found in the Western Part of Sirohi.

Change of location of basic activity.

It will be remembered that the contemporaneous basic rocks in the lower members of the Aravallis occur in the western part of the State, *viz.*, near Sirohi. Those rocks which were intruded before the Erinpura granite and which have been termed for convenience 'Delhi basic rocks', are most abundant in the eastern part of the State, the centre of basic activity changing from west to east from Aravalli to late Delhi (Ajabgarh) times. The occurrence of the Kui and Chandrawati gabbros and dolerites in the southern part of the State has already been noticed. The Mundwara suite of igneous rocks is in the western part of the State and here, also, the general suite of post-Erinpura-granite but pre-Malani basic rocks is found. Thus once again the main seat of activity changed, this time returning to the western part of Sirohi. It is indeed curious how free from basic intrusions are the large outcrops of Erinpura granite in the eastern part of the State.

Certain of the rocks included in this section may belong to the post-Malani basic suite of rocks. It is very infrequently that definite field evidence deciding the age is available. But from general appearance, size, state of decomposition and alteration, mineral contents, field relationships, etc., most of the rocks hereinafter described almost certainly belong to the post-Erinpura-granite but pre-Malani suite of basic rocks.

Older than the Deccan trap.

There is no possibility that these basaltic, doleritic and epidioritic rocks have any genetic relationship with the immense lava flows of Deccan trap in late Cretaceous times. Their antiquity is fixed by the fact that they are older than the volcanic, hypabyssal and plutonic Malani rocks which will be described in the next three chapters. One can only be amazed that time has treated the majority of these rocks so lightly.

Hypersthene-olivine-dolerite.

Perhaps the most interesting of the doleritic rocks is the hypersthene-olivine-dolerite [1] (17035) from three-quarters of a mile N. N. W. of Badala (sheet 117). As has been noted in a previous paper,[2] most of the felspars in this rock are zoned. Two large individuals forming an albite twin have a composition of 58 per cent. An. The inner parts of these individuals are more basic and

[1] *Cf.* A. Osann, 'Rosenbusch's Elemente der Gesteinslehre', Stuttgart, pp. 428-429, (1923).
[2] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, pp. 169-171, (1931).

also differ in composition, being 70 and 75 per cent. An in composition respectively. In another instance of two individuals in the position of the complex albite-Carlsbad A, one individual is zoned, that part adjacent to the twinning plane having a composition of 68 per cent. An, the same as that of the other individual; the other part of the first individual possesses a composition of 59 per cent. An.

The hypersthene possesses straight extinction in prismatic sections and has the pleochroism:—

$\mathfrak{a}$ =yellowish brown,
$\mathfrak{b}$ =reddish brown,
$\mathfrak{c}$ =dirty greenish brown.
Absorption:—$\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$

It shows characteristic small black inclusions of iron-ore.[1]

The olivine in the rock is irregular in shape. Biotite is fairly common, having the following pleochroism:—

$\mathfrak{a}$ =colourless.
$\mathfrak{b}$ =reddish brown.
$\mathfrak{c}$ =reddish brown.
Absorption:—$\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$

The slide contains other micaceous minerals and also some augite.

Olivine-basalt.

Olivine is rather a rare constituent of these post-Erinpura but pre-Malani basic rocks. It was noted in the olivine-basalt (36/72, 17047; specific gravity, 3·01) occurring two miles W. N. W. of Telpur (sheet 95); its colour is reddish brown, showing it to contain abundant iron and possibly some manganese. Thus the mineral in question may be fayalite, though it is positive in optical character. The rock contains an excellent example of a fourling Baveno twin[2] (*see* Plate 9, fig. 2), due to the combination of right and left Baveno twins. The laths forming the fourling are also twinned according to the Carlsbad law. The rock is generally fine-grained, but certain of the plagioclases and the olivines are larger in size than the groundmass.

Thin veins of basalts.

Some of these basic rocks intruding the Erinpura granite are fine-grained. They usually occur in thin ramifying veins and dykes, the magma of which must have had great fluidity at the time of intrusion. There is usually little contact metamorphic effect upon the intruded granite and the chilled margins of the dykes are narrow. The illustrat-

[1] J. P. Iddings, 'Rock Minerals', London, pp. 305-306, (1911).
[2] J. P. Iddings, *op. cit.*, p. 209.

ions of Plate 1 (fig. 2) and Plate 2 (fig. 1) show the nature of these occurrences. There are ten dykes at one locality within a total width of 10 feet 6 inches. The intruded granite was noted to be slightly schistose for a depth of half an inch from the margin of the basalt. Hand specimens and sections from the photographed occurrence (42/218, 21119), 1¼ miles west, a little south, of Karjara khera (sheet 96) show a fine-grained rock with large and small laths of plagioclase felspar, with iron-ore, set in a dark brown glass and masses of pale green serpentinous and chloritic material.

Karjara khera dolerite.

Figure 7 shows diagrammatically the relations between a larger dyke, doleritic in nature, and the Erinpura granite, which it intrudes in the hill half a mile west of Karjara khera. The dolerite follows the major joints in the granite. Debris masks the relations between the Malani porphyritic rock (42/202, 21121) and the dolerite (42/203, 21102), but there seems to be little doubt that the porphyry is much younger than the dolerite.

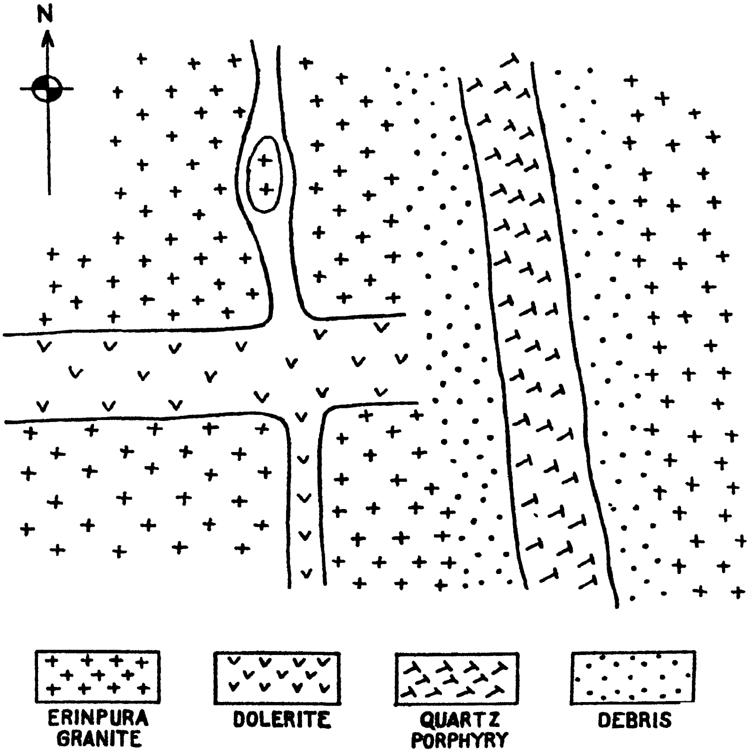

FIG. 7.—Sketch map of area one mile west of Karjara khera (sheet 96).

The dolerite contains large white crystals of felspar, usually simply twinned. The plagioclase laths are of the usual basic type and it seems possible that the large crystals had an origin different from that of the plagioclase laths. Other examples will be given in illustration of this point. The augite of the dolerite is distinctly titaniferous.

Inclusions of felspars in a dolerite.

One mile south of Phalaudi (sheet 95), large crystals of orthoclase up to seven inches in length (42/253, 21159) were observed in a dolerite (42/252, 21158) which is intrusive into Erinpura granite. The dolerite is otherwise of normal type. It is suggested as a possibility that these large crystals of felspar were derived from the Erinpura granite intruded by the dolerite. It may be that the Erinpura granite in its deepest regions had not yet completely cooled and crystallised when the basic rocks were intruded, and the basic magma, in its passage through the semi-solid rock, caught up the large felspars. Most of these are idiomorphic, but microscopic examination of the edges of the crystals indicates corrosion to have taken place.

Support to this view is given by the occurrence half a mile W. S. W. of Balda (sheet 95) of a basaltic dyke (42/312, 21228) with included fragments of quartz and felspar, all of which are corroded. Large crystals of felspar up to five inches in length, together with quartz and epidote, were noted in a chloritised dolerite (42/174 21061) occurring in Erinpura granite one mile west of Sirori (sheet 96).

Metamorphism of basic rocks by the Idar granite and its porphyries.

Evidence of metamorphism of these post-Erinpura-granite but pre-Malani basic rocks by the Idar granite and its porphyries of Malani age is not very common, so the following examples have added interest.

Amphibolite.

A section (17053) of a basic rock, best termed an amphibolite, which occurs two miles south-west of Isri (sheet 96) in a small remnant of Erinpura granite which was subjected to the metamorphosing agencies of the Idar granite, contains abundant hornblende, kaolinised felspar, iron-ore and a little quartz.

Included fragments of dolerite in a felspar-porphyry.

Included fragments of a long doleritic dyke (20906; 17068), running practically north and south a little west of the village of Danta (sheet 95), were noted in a felspar-porphyry dyke which cuts that dolerite. The black fragments of the dolerite show up well

in contrast to the lighter coloured felspar-poryphyry (*see* Plate 3, fig. 1). There is no doubt that the felspar-porphyry is younger than the dolerite, which itself intrudes Erinpura granite. Sections of the dolerite show that uralitisation of the original slightly titaniferous augite has taken place, though abundant augite and some orthorhombic pyroxene are still preserved.

Doleritic rocks with titaniferous augite and saussuritised felspar (17073) were noted by the author east of Danta, and Dr. A. M. Heron collected specimens from half a mile north-west (20909), and close to the felspar-porphyry (20907) on the north-west edge of the village. A section (20908) of an xenolith in the felspar-porphyry near the last occurrence is suggestive of its being an included fragment of the last-mentioned dolerite.

Dr. Heron collected two other specimens of basic rocks intrusive into the Erinpura granite in this vicinity, both occurring three-quarters of a mile south-west of Sindret near the temple on the Erinpura-Anadra road. The first (20910) is fine-grained and could be termed an altered dolerite; the second is coarser and is an epidiorite.

The relations between thin basaltic veins (21221), Erinpura granite and a felspar-porphyry occurring one mile N.N.E. of Bilangri (sheet 95) are clearly shown in figure 1 of Plate 2. The Erinpura granite is of aplitic type and is intruded by the basaltic dykes, which contain fragments of it; later the granite and basalts were intruded by the Malani felspar-porphyry. Fragments of the basic rock and of the granite were noted in the porphyry.

Bilangri.

On the eastern side of the porphyritic Idar granite 1¾ miles S. S. W. of Pardi (sheet 95), a peculiar rock has resulted from the picking up of fragments of a post-Erinpura-granite basic rock by the Idar granite during its intrusion. The rock is illustrated in Plate 2, figure 2.

Pardi.

Yet another example (Plate 8, fig. 1) was noted two miles east of Phacharia (sheet 95), but in this case, the enclosing granite is apparently Erinpura and not Idar. Unless the fragments of basic rock (42/255, 21161) included in the granite belong to the Delhi basic rocks, the only probable explanation of the occurrence appears to be that the basic rock in question was intruded into still molten Erinpura granite, and that subsequent movements within the granite shattered it.

Phacharia.

The author favours this explanation in view of the somewhat analogous occurrences at Phalaudi and Balda described previously.

Other specimens from sheet 95.

Other specimens collected on sheet 95 include an epidotised and zoisitised basalt (42/266, 21172) from one mile south of Sarthara; a dolerite (42/302, 21215) occurring between the Idar and Erinpura granites $1\frac{1}{2}$ miles S. S. W. of Mamauli; an altered dolerite (42/310, 21226) from $1\frac{1}{4}$ miles east of Kuma; a coarser-grained dolerite (42/311, 21227) with titaniferous augite of small optic axial angle from one mile N. N. E. of the same village; another altered coarse-grained dolerite (42/224, 21126) with abundant apatite from a quarter of a mile south of this village; an altered dolerite (42/199, 21096) with abundant iron-ore from one mile south of Amlari; and an epidiorite (36/51, 17020) from east of Sirohi. All these specimens are intrusive into Erinpura granite.

Other specimens from sheet 96.

Similar rocks were noted in that part of Sirohi lying on sheet 96. Specimens collected include an altered dolerite (20899) with titaniferous augite, from just south-west of Sanwara (collected by Dr. Heron); a basalt (21060), eight feet wide, from just south-east of Pamera; an altered dolerite, of specific gravity 3·00 and with titaniferous augite, from $1\frac{1}{2}$ miles N. N. W. of the last village; an epidiorite (42/172, 21066) from $1\frac{1}{2}$ miles E. S. E. of Nagani, already mentioned as being intrusive into a Delhi amphibolitic rock (42/175, 21065) (*see* p. 53); an epidiorite (21072) with abundant secondary quartz from a quarter of a mile north-west of Bhomra; another epidiorite (36/811, 17621) from one mile south-west of Dhauli; an altered dolerite (42/316, 21232) from $2\frac{1}{2}$ miles north-east of Nagani; a dolerite (42/200, 21097) with titaniferous augite from $1\frac{3}{4}$ miles north-west of Dhan; an altered dolerite (21112) with abundant iron-ore from $2\frac{1}{2}$ miles north-west of Dantrai; and finally, an altered dolerite (42/183, 21075) with titaniferous augite and of specific gravity 2·95 from Dungrari village.

The last mentioned occurrence is interesting. The Erinpura granite at Dungrari (42/185, 21093) is very coarse-grained with large phenocrysts of felspar and with biotite. It is profusely intruded by basic dykes. In the west side of the hill behind the village, there is a pit dug along the junction of the granite with a basic dyke which must be of fair magnitude as the granite is amphibolitised for a distance of at least five feet from the dyke. The

resultant rock (42/184, 21076) is composed of a graphic intergrowth of quartz and orthoclase, together with laths of plagioclase, some calcite and numerous prisms of hornblende.

Sheet 76.

One specimen was collected from sheet 76; this is an altered dolerite (36/808, 17616), with twinned augite, which intrudes Erinpura granite one mile E. N. E. of Rajpura.

These post-Erinpura-granite but pre-Malani basic rocks follow no general strike as a rule; but in certain areas, an imperfect parallelism can be made out. Thus on sheet 95, south-west of Amlari, the doleritic rocks have a more or less general N. W.-S. E. trend. This changes to W. S. W.-E. N. E. south of Sanpura. Other strikes are met further east. The pre-Malani basic rocks thus do not appear to have had their passage through the rocks they intrude determined by any well-defined series of fissures, joints or fault-planes.

No general strike.

CHAPTER VIII.

MALANI SYSTEM.

Nomenclature.

The term 'Malani beds' was given by Blanford to a volcanic series of rocks in Western Rajputana, particularly in the Malani district of Jodhpur State.[1] La Touche[2] has written an excellent description of the rocks of Western Rajputana, paying marked attention to the Malani series. Frequent reference will be made in this chapter to La Touche's able work. It is considered that these Malani rocks, so widespread in Jodhpur and so well-developed in Sirohi, to say nothing of their plutonic and hypabyssal facies in Idar State and other localities, are of sufficient importance to warrant the use of the term 'Malani system'. As will be seen, the Malani rocks cannot be included in the Delhi system, than which they are much younger. According to La Touche:—[3]

Age of Malani rocks.

'After the eruption of the Malani lavas a considerable period of time may have elapsed before the sandstones of the Vindhyan system were deposited upon them. The evidence of unconformability is not so clear as in the case of the junction between the schists and sandstones, for as it happens the sandstones are never seen in contact with the lavas in places where the latter have been disturbed, but wherever the two formations occur together they are both nearly horizontal. On the other hand there is clear evidence that the lavas were subjected to a long period of erosion and weathering before the deposition of the sandstones. In the scarps north of the city of Jodhpur numerous sections of the junction are exposed, in which the sandstones are seen to rest upon a very uneven floor of the lavas. This in itself would not be evidence of unconformability, for the surface of the lava flows was probably originally irregular, as is usual with such viscous lavas as these, but the sand tones can sometimes be seen banked up against denuded and scarped edges of the flows. Moreover, at the base of the sandstones there is frequently a layer of varying thickness in which large blocks of the lava are imbedded in silt and grit. These are not waterworn boulders, transported from a distance, but are always of the same variety of lava as that composing the sheet immediately underlying them, and they have evidently been weathered out *in situ*, and then quietly buried in silt. Again, the upper portion of the lava flows, where they are exposed beneath the scarps of sandstone, is usually found to be weathered to a considerable depth, so that the lava has become quite soft and rotten. This weathering of the

[1] *Rec. Geol. Surv. Ind.*, X, p. 17, (1877).
[2] *Mem. Geol. Surv. Ind.*, XXXV, pp. 1-116, (1902).
[3] *Op. cit.*, pp. 26, 27.

surface of the lavas is not observed where they are not protected by the sandstone, and evidently took place before the latter was deposited, and judging from the effects of atmospheric agencies on the lavas at the present time, it must have taken a very long period to produce the results noted on such slowly altered rocks as these. Lastly, in a few places patches of true conglomerate, containing waterworn and well rolled pebbles and boulders of the lavas, mingled with pebbles of other crystalline rocks, and transported from a distance, are found occupying hollows in the uneven surface of the lava flows, and underlying the sandstones. These are associated with beds of fine red and green shales also of quite local occurrence.'

Method of description.

Accordingly throughout this memoir, the term 'Malani system' may be taken as including all those rocks, plutonic, hypabyssal, volcanic and tuffaceous in nature, with their associated rocks that are intermediate in age between the Delhi and Vindhyan systems, and are thus either late Purana or early Palæozoic in age. The plutonic representatives of the Malani system will first be described and then the hypabyssal and volcanic representatives. The interrelationship between these rocks will then be discussed in detail, utilising such analyses as are available.

Plutonic Rocks: Idar Granite.

Jalor and Siwana granites.

The plutonic rocks associated with the Malani volcanics in Jodhpur have been given by La Touche the names of Jalor and Siwana granites.[1] La Touche describes the Siwana granite as containing

'an abundance of actinolitic hornblende, usually of a bright green colour but sometimes with a bluish tinge; its pleochroism is usually very strong. It is commonly interstitial, but occasionally occurs in idiomorphic crystals, especially in the veins and dykes protruded from the main mass into the surrounding rhyolites. The felspar and quartz frequently form a micropegmatitic intergrowth or granophyric structure of great beauty. There seems to be a singular dearth of accessory minerals in this granite; even magnetite is rare.'

He adds that

'the Jalor granite differs from that just described mainly in containing mica as the principal ferromagnesian constituent instead of hornblende. There is also a fair proportion of plagioclase felspar as well as orthoclase. The mica is of two kinds, muscovite and biotite. The former predominates in a specimen from Manpur near Pali, No. 12·258, while biotite alone occurs in the granite of Jalor hill, No. 11·716.'

Middlemiss' Idar granite[2] is very similar to the Jalor and Siwana granites and he has used the term 'Idar granite' comprehensively

[1] *Op. cit.*, pp. 16, 24-25, 90-91.
[2] *Mem. Geol. Surv. Ind.*, XLIV, pp. 115-131, (1921).

to embrace all three granites. Accordingly there is no point in the invention of yet another name, such as 'Malani granite', to embrace all these Malani granites and their representatives, the Ban, Isri and other granites of the same age in Sirohi State, when the term 'Idar granite' has already been used in a comprehensive sense.

Sirohi representatives.

The representatives of the Idar granite in Sirohi State have been discussed under the following subheadings:—

1. Ban outcrops.
2. Isri outcrops.
3. Nandwar and Sunda hills.
4. Porphyritic Idar granites and other small occurrences of normal Idar granite.

Ban Outcrops.

Mapped by Hacket.

Mention has been made in Chapter I (*see* p. 10) of the granite, occurring with the rhyolites near Ban (sheet 94), which Hacket referred to the Erinpura granite. This Ban granite[1] occurs as a number of isolated masses cropping out in sand and alluvium in the south-eastern corner of sheet 94. The most important outcrop forms the southern part of the ridge ending with the peaks of 2,181 feet and 1,609 feet. This is intrusive into Aravalli shales and slates north-west of Mosal and is separated by an hypabyssal facies (granite-porphyry; 36/63, 17031) from the rhyolites forming the northern part of the ridge in question.

Minerals present.

A specimen (36/61, 17029) of this granite from two miles E. S. E. of Ban has a specific gravity of 2·64. It is a coarsely crystalline, light-coloured potash-granite containing quartz, orthoclase, biotite and a little plagioclase, hornblende and muscovite, with accessory zircon. Some orthoclase is graphically intergrown with quartz. Orthoclase microperthite is also present. The rock thus resembles the Jalor type of La Touche, biotite being predominant over hornblende.

Ban Hill.

The large hill culminating in the peak of 2,098 feet, which lies to the south of Ban, is also composed of Idar granite. A typical specimen (36/60, 17028) was analysed with the results given in Table VI on page 107. These results are discussed on page 108. Under the microscope, the rock is seen to be composed of the same minerals as were noted in 17029.

[1] *Rec. Geol. Surv. Ind.*, LX, pp. 113-114, (1928).

A small exposure of granite was noted in the northern part of hill station 1,320 feet to the north-west of Andor. This is a coarse-grained rock which crumbles easily. It contains abundant quartz and pink orthoclase, biotite being the ferromagnesian mineral. It possesses no foliation. The granite is better developed in the hills near Euri and also north-west of Andor. Some 1¼ miles north-west of the latter village, the granite shows little nodules projecting from its otherwise smooth surface. A section (17023) of one of these contains abundant tourmaline, strongly pleochroic, with quartz, orthoclase, albite, muscovite and fluorspar, light purple in thin section and riddled with inclusions of iron oxide. Measurements by the Federov stage showed that a Carlsbad twin had a composition of about 2 per cent. An.

Andor.

Other outcrops of granite occur in the vicinity of Bheu and in the hills east of Mosal.

Other outcrops.

The Idar granite, as generally developed in this part of Sirohi, is a coarsely crystalline rock with no foliation, though jointing is rather well developed at times, as *e.g.*, in the hills near Euri. The characteristically rounded forms are the result of normal weathering, greatly assisted by wind erosion (*see* Plate 7, fig. 1, and Plate 8, fig. 2). The difference between the smooth rounded tors of Idar granite and the rugged jointed hills of rhyolite forms a striking feature of the scenery.

Weathering.

Isri Outcrops.

The Idar granite occurring near Isri has been described briefly elsewhere.[1] It occurs in those parts of Sirohi state on sheets 95 and 96 which are west of Isri (sheet 96). It intrudes the ancient Aravallis and also the Erinpura granite more or less at the contact between these rocks. It is quite unfoliated and forms characteristically rounded hills, very reminiscent of those formed by the Ban granite which is of the same age and mineralogically akin (*see* Plate 6, fig. 2).

Locality.

The chief mineralogical characteristic of this Isri granite is the possession of graphic intergrowths of quartz and orthoclase which generally form the greater part of the groundmass of the rock. This feature is entirely absent in the Erinpura granite proper, apart

Characteristic presence of graphic intergrowths.

[1] *Rec. Geol. Surv. Ind.*, LXI, p. 114, (1928).

from its pegmatites, but though not typical in the Ban outcrops, it has been noted by La Touche as occurring frequently in the granites of Jalor and Siwana in Jodhpur, and by Middlemiss in the Idar granite of Idar State. The specimens (36/75, 17050; 36/128, 17110) from two miles south-west of Isri and from one mile south east of Mirpur (sheet 95) show this structure. It frequently happens that the disparity in size between the groundmass and the large felspar and quartz crystals is such that the rock could be termed a porphyry, or, better, a porphyritic granite (36/76, 17051; from half a mile south-west of Isri). Most of these porphyritic granites occur as dykes rather than plugs or bosses; these occurrences will be described under the fourth subheading.

Muscovite rare.

Muscovite is a rare constituent of the Isri outcrops. It was noted in a specimen (17052) from 2¾ miles south-west of Isri, the rock being much finer-grained than another specimen (17092) from the north-eastern end of the Sindret ridge. This latter somewhat resembles the muscovite-granite (12/258) from Manpur, near Pali, described by La Touche.

Biotite more common than hornblende.

Both biotite and hornblende are common but the former mineral predominates over the latter. Specimens (17050 and 17054) of biotite-granite were collected from two and from three miles south-west of Isri. Dr. A. M. Heron collected a specimen (20901) from the Idar granite in the valley with temples, north of hill station 2,181 feet, one mile south-east of Mirpur. The biotite is frequently altered to chlorite and the felspars are sericitised.

Fluorite.

The occasional presence of fluorite in the Ban outcrops has been noted above. Fluorite is also not abundant in the Isri outcrops. It was noted in the granite (36/77, 17055; specific gravity, 2·61) from two miles west of Isri. It occurs in an analysed specimen (36/128, 17110) from the foot of hill station 2,181 feet, one mile south-east of Mirpur and in one (42/317, 21214; specific gravity, 2·60) from 1¼ miles east, a little south, of the same village. The biotite of the last specimen is crowded with inclusions of iron-ore.

Analyses.

The results of the analysis by Mons. F. Raoult of the potash-granite (36/128) from the foot of hill station 2,181 feet, one mile south-east of Mirpur (sheet 95), are given in Table VI, which follows, together with those of an analysis by the same gentleman of a potash-granite (36/80) from

Ban (sheet 94). Both these analyses, and their mean, may be compared with that by Dr. W. A. K. Christie of a hornblende-granite from Kawa in Idar State, collected by Middlemiss, and with Rosenbusch's average of twelve analyses of alkaline granites. The author is unaware of any published analysis of the Idar granite other than that by Dr. Christie mentioned above.

TABLE VI.

—	36/60	36/128	A	B	C
	Per cent.	Per cent.		Per cent.	Per cent.
$Si O_2$	75·46	74·64	75·05	73·30	66·04
$Ti O_2$	0·52	0·40	0·46	0·11	0·69
$Al_2 O_3$	11·11	12·06	11·58	12·33	14·77
$Fe_2 O_3$	0·11	0·07	0·09	2·58	1·18
$Fe_2 O_3$	2·24	1·90	2·07	1·28	4·41
Mn O	0·09	0·05	0·07	0·02	0·11
Mg O	0·18	0·07	0·13	0·26	0·98
Ca O	1·16	1·12	1·14	0·46	2·95
$Na_2 O$	2·75	3·38	3·06	4·55	2·56
$K_2 O$	5·64	5·60	5·62	4·20	5·25
$H_2 O$—105°C.	0·28	0·20	0·24	..	0·21[1]
$H_2 O$+105°C.	0·51	0·78	0·65	0·86	0·71[2]
$P_2 O_5$	*trace*	0·05	0·02	0·05	*trace*
Other constituents	..	..	..	..	0·05
TOTALS	100·05	100·32	100·18	100·00	99·91
Specific gravities	2·647	2·612	2·63	..	2·72

36/60. Potash-granite, Ban (sheet 94), Sirohi State (F. Raoult).
36/128. Potash-granite, foot of hill station 2,181 feet, one mile south-east of Mirpur (sheet 95), Sirohi State (F. Raoult).
A. Mean composition of 36/60 and 36/128.
B. Rosenbusch's average of twelve alkaline granites. [3]
C. Hornblende-granite, Kawa, Idar State (W. A. K. Christie).[4]

[1] —108° C.
[2] +108° C.
[3] As quoted by R. A. Daly, 'Natural History of Igneous Rocks', New York, p. 20, (1914).
[4] *Mem. Geol. Surv. Ind.*, XLIV, p. 121, (1921).

It will be seen from Table VI that the specimens of Idar granite from Ban and Mirpur (Isri) are more or less normal alkaline (potash-) granites. The silica and potash percentages are slightly higher than those in Rosenbusch's average alkaline granite, whilst the soda is slightly less. Comparison of the analyses with that of the hornblende-granite from Kawa indicates that the latter is definitely more basic than the Sirohi representatives of the Idar granite. This variation in composition approaches that of the Erinpura granite as indicated by the analyses in Table II on page 59. A rather surprising result is that the mean of the two analyses of Erinpura granite from Trevor Tal (Abu) and Waloria very closely approximates to the mean of the two analyses of the much younger Idar granite from Ban and Mirpur.

Study of analyses.

Nandwar Hill and the Sunda Hills.

The granite cropping out in Nandwar Hill and the Sunda hills has many features of interest. The hills in question are found in the south-eastern corner of sheet 75, lying principally in Jodhpur State; the north-eastern corner of sheet 76 and the north-western corner of sheet 96, both in Sirohi State. Certain of the localities mentioned hereafter are in Jodhpur as it was necessary to examine certain occurrences across the border in order to understand the relationships of the rocks forming the hills.

Locality.

The Sunda hills (*see* Plate 5, fig. 2) culminate south-west of Jaswantpura (sheet 75) in the peak of 3,252 feet. They form a very conspicuous landmark and, taken in conjunction with Nandwar Hill (*see* Plate 5, fig. 1) to the south, they bear comparison in size with the *massif* of Mount Abu.[1] Nandwar Hill rises to heights of 3,220 and 3,277 feet in two peaks on sheet 96, almost at its junction with sheet 76. There is a bungalow on the Sunda hills but no such building exists on Nandwar Hill; nor is this to be wondered at when one ascends the steep precipitous slopes of the latter.

Elevation.

About half of the 4¾ square miles of Sirohi on sheet 75 is occupied by Idar granite. The greater portion of the remainder consists of sand and alluvium, with some Erinpura granite is clearly intruded by the Idar granite

Sketch map.

[1] It must be remembered that the granite composing these hills is the Idar granite, which is much younger in age than the Erinpura granite forming Mount Abu.

in its various modifications. The evidence of this is better seen in the extreme north-eastern corner of sheet 76, in the vicinity of the Sirohi villages of Anapura and Nimach. A geological sketch map of the area in question, embracing parts of the four one inch sheets, 75, 76, 95 and 96, is given below as Figure 8.

FIG. 8.—Geological sketch map of the parts of Jodhpur and Sirohi States at the junction of the one-inch map sheets 75, 76, 95 and 96. The longitude given is that of the one-inch sheets.

The Erinpura granite occurring in the 'bays' of Idar granite south of Anapura (sheet 76) is highly crushed and altered. It is intruded by its pegmatite and also by basic dykes. The Idar granite on the other hand is free from pegmatite and basic dykes. The tongues of Idar granite stretching N. N. W. from south of Anapura and S. S. E. to south-east from south of Uchmat (sheet 75) in Jodhpur are of the type designated porphyritic granite (see p. 112).

Field relations.

indicate that the cooling granitic magma was subjected to severe strain during the cooling process, more particularly so for the latter specimen. The same features were noted in two specimens (42/304, 21217; 42/305, 21218) from 1½ miles south-east and 2¼ miles S. S. E. of Mirpur (sheet 95). They are marginal facies of the granite which show brecciation and possess a certain similarity with rhyolitic types (36/123, 17104) from a little further north, *viz.*, south of Varela (sheet 95).

Porphyritic granitic types were noted in the tongues of Idar granite between Uchmat (sheet 75) and Nimach (sheet 76). These are similar in appearance under the microscope to the examples noted above as occurring in the Isri outcrops. Typical specimens were collected from half a mile south of Uchmat (42/208, 21108) and one mile south-east of the same village (42/209, 21109). The latter specimen has a specific gravity of 2·71.

Sunda hills and Nandwar Hill.

Four more or less parallel occurrences were noted in that south-eastern part of Jodhpur in the extreme south-western corner of sheet 95. The largest of these, culminating in the peak 1,089 feet, runs S. S. E. just across the border into Sirohi State. The northernmost hills trend more S.E.–N.W.

Other occurrences on sheet 95.

Three dykes running N.N.E.–S.S.W. were noted near Motagaun. Specimens of these porphyritic granites (42/256, 21162; 42/257, 21163) contain large crystals of quartz, orthoclase and plagioclase, set in a moderately coarse eutectic of the first two minerals. Biotite is the ferromagnesian mineral. A certain amount of calcite is present. The latter specimen has a specific gravity of 2·62. A photomicrograph of the section (21163) of this is shown as figure 1 of Plate 10.

A set of five specimens was collected from half a mile south-east of Kalandari village. These (42/260-264, 21166-70) occur in the low ground between two streams and their relations with the Erinpura granite are obscured by alluvium. They vary in colour from flesh to pink. They are all coarse-grained, normal granites containing quartz, orthoclase, muscovite and biotite largely altered to chlorite, some calcite and a little iron-ore. Some micrographic intergrowth of quartz and orthoclase exists. The specific gravities of the last four specimens are 2·62, 2·76, 2·62 and 2·64 respectively.

The low range of hills south-east of Phacharia, which trends N.E.–S.W., is formed of a moderately fine-grained, light-coloured granite (42/254, 21160), chiefly composed of quartz and orthoclase.

There are several hills in the vicinity of Siloi, trending more or less N.N.E.–S.S.W., which are composed of pink porphyritic Idar granite. Particular mention may be made of the hill one mile south, and of hill station 1,408 feet, 1½ miles S. S. W., of the village. Specimens from the former hill (42/274, 21181; 42/275, 21182) show porphyritic granites with abundant fine flakes of biotite and a certain amount of iron-ore. A slickensided surface of the Idar granite was noted in hill 1,408 feet. It would appear from such evidence as is available in the field that the intrusion of these dykes of Idar granite was accompanied by faulting in many cases.

The felspars of a specimen (42/307, 21223) from further south of the above occurrences, *viz.*, one mile north-east of Balda, are sericitised, the rock having a greenish appearance in consequence.

A few dolerites intrude the Idar granite in the hill two miles south-west of Mamauli; but the granite breaks the continuity of a quartz pegmatite vein intruding the Erinpura granite of this region and hence is Idar-, not Erinpura-granite, in age. A specimen (42/277, 21184) from 2½ miles south-west of the same village resembles the Siloi and other porphyritic granites, but contains an appreciable amount of plagioclase (21184 B). Another specimen (42/303, 21216) was collected from 1½ miles S.S.W. of Mamauli.

Other occurrences on sheet 96.

The pink granite forming hill station 1,185 feet, S.S.W. of Bilangri, varies greatly in texture:- that part forming the hill proper is a porphyritic granite; the northern and southern extensions are felspar-porphyries. A ridge composed of porphyritic Idar granite runs approximately north from one mile north-west of Harni in the north-western corner of the sheet. Specimens (42/212, 21113; 42/213, 21114) have the usual pink colour due to large orthoclase crystals. The ridge is shown as figure 2 of Plate 7. What appears in the field to be a fault rock (42/214, 21115) occurs on the western side of the granite ridge, some 1½ miles W. N. W. of Harni. The section, however, shows a chloritised, and somewhat crushed, hornblendic porphyritic granite.

The ridge running north from the little village of Warkan and containing the peak of 1,024 feet, is composed of a coarse, porphyritic form of Idar granite, similar to that forming the northerly

indicate that the cooling granitic magma was subjected to severe strain during the cooling process, more particularly so for the latter specimen. The same features were noted in two specimens (42/304, 21217; 42/305, 21218) from 1½ miles south-east and 2¼ miles S. S. E. of Mirpur (sheet 95). They are marginal facies of the granite which show brecciation and possess a certain similarity with rhyolitic types (36/123, 17104) from a little further north, *viz.*, south of Varela (sheet 95).

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The ridge running north from the little village of Warkan and containing the peak of 1,024 feet, is composed of a coarse, porphyritic form of Idar granite, similar to that forming the northerly

trending ridge with the hill station 1,188 feet to the north-east. The parallel ridges near Sanwara are granite-porphyries rather than porphyritic granites, but the southernmost one, between Sirori and Palri, is of the latter type (21058). The short ridge, also trending northerly, adjacent to the village of Selwara, is composed of a biotitic porphyritic granite (42/177, 21068). Three ridges of porphyritic Idar granite (36/802, 17609) occur near the deserted village of Dewari in the south-western corner of the sheet; the southernmost one is cut by two post-Malani basic dykes (*see* p. 143).

CHAPTER IX.

MALANI SYSTEM—*continued.*

HYPABYSSAL ROCKS: QUARTZ-PORPHYRIES, QUARTZ-FELSPAR-PORPHYRIES, FELSPAR-PORPHYRIES, GRANITE-PORPHYRIES, GRANOPHYRES AND MICROGRANITES.

Outcrops. Rocks of Malani age, classed as hypabyssal in nature, occur in Sirohi State as under:—

1. Ban area (sheet 94).
2. Danta-Sindret area (sheet 95).
3. Undwaria area (sheet 96).
4. Other occurrences on sheet 95.
5. Other occurrences on sheet 96.

Ban Area (Sheet 94).

Reference has been made (p. 104) to a granite-porphyry occurring two miles north of Ban, which is regarded as a marginal phase of the Ban granite. **Ban.** This (36/63, 17031) has the same specific gravity (2·64) as the Ban granite. It contains a fair amount of muscovite.

Andor. It is possible that the specimens from Andor (36/70, 17038; 17040) referred to the Erinpura granite (*see* p. 61) are Malani in age.

Danta-Sindret Area (Sheet 95).

A remarkably well-developed system of porphyry dykes penetrates the Erinpura granite in the vicinity of the villages of Danta and Sindret. **Sketch map.** The general trend of the dykes near Danta is about 110° (W.N.W.–E.S.E.) Those occurring to the west and north of Danta may be seen in the

geological sketch map of Danta and Sindret, embracing part of Pamta Hill, which forms Figure 9.

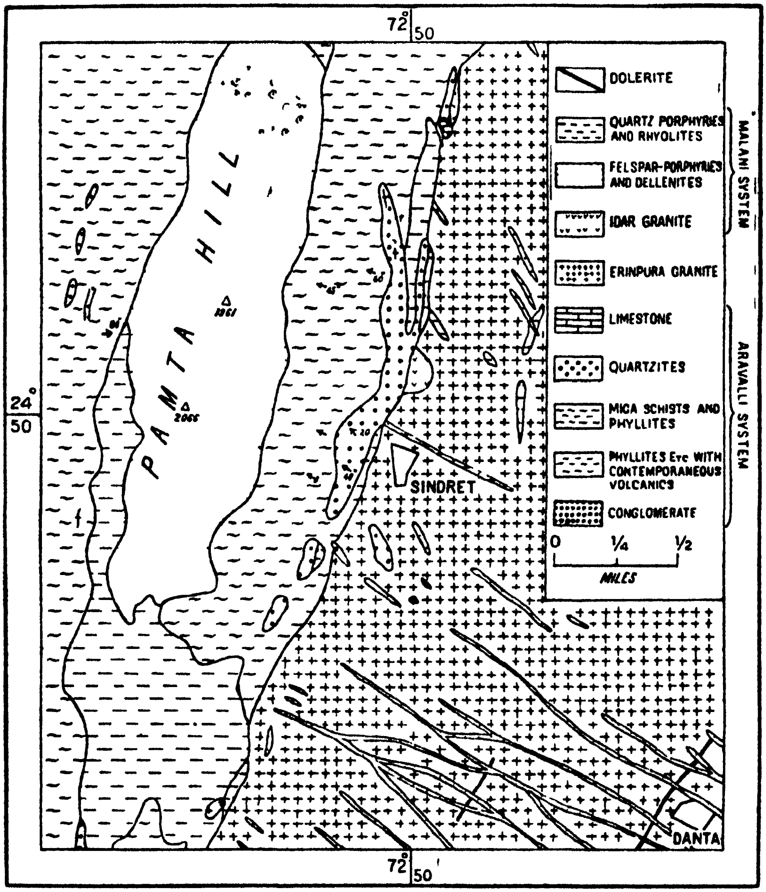

FIG. 9.—Geological sketch map of the Danta-Sindret area, embracing part of Pamta Hill (sheet 95). The longitude is that of the one-inch sheet.

Age.

The age of these felspar porphyries is fixed by the facts that they are everywhere intrusive into the Erinpura granite and that they are associated with rhyolites, dellenites and Idar granite of Malani age Just west of the village of Danta, there is a dolerite dyke (20906; 17068) mentioned previously (*see* pp. 98-99) as being intrusive in the Erinpura granite; this dolerite dyke is older than the Malani felspar-porphyry dykes which cut it and which include fragments of it.

Analyses.

An analysis by Mons. F. Raoult of a quartz-felspar-porphyry (36/97, 17076) from one mile north-west of Danta, and other analyses of related Sirohi rocks and rocks from other countries, are given in Table VII.

TABLE VII.

...	36/97	36/119	36/128	36/65	36/60	A	B	C
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	69·98	70·62	74·64	74·80	75·46	72·60	69·44	69·93
TiO_2	0·81	0·78	0·40	*trace*	0·52	0·30	..	0·33
Al_2O_3	12·92	13·24	12·06	13·05	11·11	13·88	15·21	14·95
Fe_2O_3	0·31	2·37	0·07	0·35	0·11	1·43	1·74	1·78
FeO	3·71	1·71	1·90	1·17	2·24	0·82	0·56	0·55
MnO	0·10	*trace*	0·05	0·04	0·09	0·12	..	*trace*
MgO	0·80	0·85	0·07	0·11	0·18	0·38	0·93	0·60
CaO	1·16	0·98	1·12	0·94	1·16	1·32	1·90	1·46
Na_2O	2·68	2·71	3·38	4·16	2·75	3·54	5·11	5·30
K_2O	5·62	5·28	5·60	4·58	5·64	4·03	4·53	3·99
H_2O—105° C. . . .	0·19	0·31	0·20	0·21	0·28	..	..	..
H_2O+105° C. . . .	1·56	1·38	0·78	0·83	0·51	1·52	0·77	0·44
CO_2	0·18	0·12	..	*trace*	..	..	..	..
P_2O_5	0·07	0·11	0·05	..	*trace*	0·06	..	0·33
Other constituents .	..	..	..	..	..	..	..	0·35
TOTALS . . .	100·04	100·46	100·32	100·24	100·05	100·00	100·28	100·01
Specific gravities . .	2·637	2·642	2·612	2·617	2·647	..	..	..

36/97. Quartz-felspar-porphyry, one mile north-west of Danta (sheet 95), Sirohi State (F. Raoult).

36/119. Dellenite, top of hill station 1,961 feet, one mile north-west of Sindrot (sheet 95), Sirohi State (F. Raoult).

36/128. Potash-granite, foot of hill station 2,181 feet, one mile south-east of Mirpur (sheet 95), Sirohi State (F. Raoult).

36/65. Banded rhyolite, three miles W. N. W. of Alpa (sheet 94), Sirohi State (F. Raoult).

36/60. Potash-granite, Ban (sheet 94), Sirohi State (F. Raoult).

A. Osann's average of 64 liparites, including 40 rhyolites.[1]

B. Quartz-trachyte-andesite, Porobbo, Toba Lake, Sumatra (Herz).[2]

C. Granite-porphyry, northern part of Crazy Mountains, Montana, U. S. A. (Hillebrand).[2]

[1] As quoted by R. A. Daly, 'Igneous Rocks and Their Origin', New York, p. 19, (1914).

[2] As quoted by J. P. Iddings, 'Igneous Rocks', London, II, p. 134, (1913).

It will be seen from an examination of Table VII that there is a close relationship between the analysis of the quartz-felspar-porphyry and that of the dellenite from the top of hill station 1,961 feet. As will be seen later, it is considered that the dellenites are the volcanic equivalents of the felspar-porphyries. Both analyses show a certain similarity with the analysis of the granite-porphyry from the northern part of the Crazy Mountains, Montana.

Relationship between quartz-felspar-porphyry and dellenite.

The specific gravities of these porphyries vary largely as will be seen from the following figures in which the number of the specimen is given in parenthesis:—2·637 (36/97); 2·64 (36/81); 2·72 (36/87); and 2·72 (36/90).

Specific gravities.

The mineralogical composition of the porphyries will best be understood from the following brief description of certain specimens collected in the course of the field work.

Mineralogical contents.

The analysed specimen (36/97, 17076) contains abundant corroded phenocrysts of quartz, orthoclase and fewer plagioclase crystals, set in a fine-grained groundmass of the same minerals together with some calcite and chlorite, the last mineral probably being derived from hornblende. A quartz-felspar-porphyry (36/101, 17080) from the western end of the hill a quarter of a mile east of Danta is similar to the above, but there is a strong development of a fine-grained micrographic (granophyric) intergrowth of quartz and orthoclase. The orthoclase phenocrysts show microperthitic intergrowth with albite. A specimen (36/102, 17081) from the middle of the same hill shows more pronounced perthitic intergrowth than the former specimen. Another specimen (36/103, 17082), from the eastern end of the same hill, shows larger phenocrysts of orthoclase and a crystal of iron-ore, with hexagonal boundaries, measuring 0·9 mm. across. These last three specimens, taken from the same hill, show that there is a little longitudinal variation in the same porphyry dyke.

Perthitic and micrographic intergrowth.

Lateral variation is much more pronounced, inasmuch as the edges of the dykes show the effects of chilling and are much finer-grained than specimens taken from the central portions of the same dyke. Thus a specimen (36/91, 17071) from just west of Danta village is of normal type, whereas a specimen (36/95, 17074) from the marginal facies of the same dyke shows the fine-grained chilled portion as will as the usual

Lateral variation.

coarse-grained porphyry. The chilled margin is as a rule less than one inch in width.

La Touche[1] has written of the formation of 'quartz mosaics' in the rhyolites of Western Rajputana in which secondary quartz surrounding a quartz phenocryst is in optical continuity with the quartz of the phenocryst. A somewhat similar phenomenon was observed in certain felspar-porphyries, as, for instance, in the last-mentioned example (17074). The large orthoclase phenocrysts are frequently surrounded by a rim of fine-grained material which appears to be a very fine-grained 'myrmekitic' intergrowth of ? quartz and ? orthoclase.[2] Both minerals of this intergrowth appear to extinguish with the phenocryst. It thus seems that there has been partial solution of the orthoclase phenocryst around its edges and that silica, in the form of quartz, has crystallised out in the place of the dissolved orthoclase. Accordingly the orthoclase in the rim should be in optical continuity with the phenocryst as it is really that part of its margin which has not been removed.

Micrographic intergrowth of quartz and orthoclase.

Sederholm uses the term 'myrmekite' for

> 'an intergrowth of plagioclase and vermicular quartz, generally replacing potash felspars, formed during the later or paulopost stages of consolidation, or during a subsequent period of plutonic activity.'[3]

Myrmekite.

> 'The reaction involves the liberation of silica, which appears as quartz, and of potash, which goes to form the shreds of biotite often in the neighbourhood of myrmekite.'[4]

It is impossible to state with certainty that the mineral intergrown with quartz in the section described above is orthoclase and not plagioclase; in other examples, however, it will be seen that continuity of extinction is not found and in these it is possible that the intergrowth is true myrmekite, quartz and plagioclase.

Other sections showing this phenomenon are 17071, 17060 and 17069. The bordering rim is more composite in a specimen (36/126, 17107) from one mile north-east of Mirpur and the extinction of its

[1] *Mem. Geol. Surv. Ind.*, XXXV, pp. 80-81, (1902).

[2] F. Becke, 'Zur Physiographie der Gemengteile der Krystallinen Schiefer', Vienna, pp. 38-44, (1906); also Plate 2, figs. 21 and 22. A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 183, (1931).

[3] A. Holmes, 'The Nomenclature of Petrology', London, p. 164, (1920). For a detailed discussion of the term, *see* J. J. Sederholm, *Bull. Comm. Geol. Finlande*, XLVIII, pp. 63-143, (1916).

[4] G. W. Tyrrell, 'The Principles of Petrology', London, p. 94, (1926).

various components bears no general relationship to that of the orthoclase phenocryst.

A specimen from a quarter of a mile south-east of Danta village (36/81, 17060) shows an excellent example (*see* Plate 10, fig. 2) in which the formation of the myrmekite is not restricted to the marginal portions of the orthoclase phenocryst. Certain phenocrysts in this slide have a mere central remnant of orthoclase, the whole of the outer part being composed of myrmekite. Most of the felspar phenocrysts in these rocks are orthoclase with varying amounts of perthitic and microperthitic intergrowths of acidic plagioclase, probably albite. There are, however, frequently phenocrysts of plagioclase which, as will be seen, are of about the same basicity as the plagioclases in the dellenites described hereafter (*see* pp. 134-136). Thus in a specimen (36/71, 17041) from one mile north-east of Sindret, measurements by the Federov stage of the composition of the felspar individuals forming two albite-Ala B complexes, which are in more or less parallel growth, indicate a composition of 33 per cent. An. These complexes have been described and figured elsewhere.[1]

Composition of felspars.

Another albite-Ala B complex, with pericline twinning, was noted in the felspar-porphyry (36/127, 17108) from 1¼ miles S. S. W. of Sindret. This likewise has a composition of 33 per cent. An.[2] An albite-Ala B complex and an associated albite twin of composition 35 per cent. An were noted in a porphyry (17019) from half a mile south of Khomal.[3]

However in a porphyry (36/87, 17066) from 2¼ miles south, a little west, of Danta, determination by the Federov stage of the composition of individuals forming an albite-Carlsbad complex gave results of 5 per cent. An. It is probable that this relative acidity is the result of albitisation.

Certain of the porphyries of this and other areas appear to contain chalcedony. Thus in a quartz-felspar-porphyry (36/89, 17069) from one mile west of Danta, spherules of this mineral were noted. Between crossed nicols, the chalcedony shows a cross which is parallel to the cross-wires and remains so on rotation of the nicols and cross-wires. The

Chalcedony.

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 181, (1931).
[2] A. L. Coulson, *loc. cit.*, p. 173.
[3] A. L. Coulson, *loc. cit.*, pp. 180-181.

fibres constituting the spherules generally have their elongation parallel to a, the fastest ray. Were they quartz elongated parallel to the *c* axis, this ray would always be the slowest.[1] Some of the quartz phenocrysts have a border of a fibrous mineral which is also probably chalcedony. In certain cases, the centres of the spherules of this bordering mineral appear to be located next the edge of the quartz phenocryst, the 'spherules' thus really being 'semi-spherules' which have grown radially outwards from the margin of the quartz phenocryst. Similar rims are visible in a porphyry (36/105, 17084) from half a mile E. S. E. of Sindret and in a felspar-porphyry (36/127, 17108) from 1¼ miles S. S. W. of the same village.

Somewhat similar fine-grained rims of indeterminable nature can be seen surrounding certain of the quartz phenocrysts in a specimen (36/98, 17077) from a quarter of a mile S. S. E. of Sindret. At times these doubly refracting rims are separated from the phenocrysts by an isotropic ? glassy border.

Hornblende.

Hornblende appears to be the usual ferromagnesian mineral in these porphyries from Sindret and Danta but generally it is very much altered to chloritic minerals and epidote. Fine-grained biotite, however, is sometimes predominant (17109). Quite frequently a rim of small hornblende crystals may be seen around a quartz crystal (36/95, 17070; 36/88, 17067). This is perhaps best developed in the porphyry previously mentioned (36/87, 17066) from 2¼ miles south, a little west, of Danta (*see* p. 120) where there are quartz phenocrysts possibly of two kinds. Some have rims of hornblende; these are possibly *enclaves enallogenes* or accidental inclusions of quartz. The others are normal phenocrysts of quartz which are greatly corroded. It may be noted in this connection that a specimen (17061) from a quarter of a mile south-east of Danta shows inclusions of what are possibly fragments of the Aravalli rocks.

Calcite.

Calcite is common in certain porphyries (17061). This mineral can be seen developing from felspar in a specimen (36/90, 17070) from Danta village.

Composite felspars.

Very large composite felspar phenocrysts were noted in felspar-porphyries (36/106, 17085; 17093) from one mile north-east and 1¼ miles north of Sindret respectively. They include small crystals of sphene and apatite.

[1] O. Mugge, 'Rosenbusch's Mikroskopische Physiographie der petrographische wichtigen Mineralien', Stuttgart, I, Pt. 2, p. 196, (1927).
J. P. Iddings, 'Rock Minerals', London, p. 540, (1911).

A felspar-porphyry (36/108, 17087) from 1¼ miles S. S. E. of Khomal and another (17019) mentioned previously (p. 120) as occurring half a mile south of Khomal, are very similar in appearance in hand-specimens and under the microscope to the dellenites of Pamta Hill. The former contains a considerable amount of calcite. Another porphyry (36/120, 17101) from 1½ miles south-west of Sindret, intrudes the rhyolites of the southern part of Pamta Hill; it is the hypabyssal equivalent of the dellenites which overlie the rhyolites.

Porphyries resembling dellenites.

Similarly quartz-porphyries were noted which are the hypabyssal equivalents of the rhyolites of Pamta Hill. A specimen (36/96, 17075), of specific gravity 2·62, from half a mile south of Sindret, contains abundant phenocrysts of quartz with fewer of orthoclase, set in a fine-grained siliceous matrix. Similar porphyries occur in the small hill running north from the village (36/110, 17089; from one mile north of Sindret). Another quartz-porphyry (36/104, 17083), from one mile south-west of Danta, shows the effects of shearing, a banded structure being developed.

Quartz-porphyries.

These quartz-porphyries of the Danta-Sindret area have been given the same colour as the rhyolites on the one-inch map sheets on which mapping was carried out. They are contemporaneous, both quartz-porphyries and rhyolites being slightly older than the felspar-porphyries from which they have been coloured differently. In other areas, however, quartz-porphyries grade into felspar- and granite-porphyries with which they appear to be contemporaneous; in these cases they have not been differentiated on the map.

Mapping of quartz-porphyries.

A rather more basic porphyry (17059) was noted 1½ miles north-west of Attaji ka Mul. This contains phenocrysts of felspar with fine-grained rims as described previously and, also, abundant hornblende in prisms of varying size, set in a rather coarse felspathic and quartzose matrix with a fair amount of iron-ore.

More basic porphyry.

Undwaria Area (Sheet 96).

Porphyries are found in the vicinity of the small village of Undwaria, south-east of the larger village of Sanwara on the road from Sirohi to Anadra. The general strike of the felspar-porphyries in this area is more or less

Locality and strike.

that of the similar rocks occurring near Danta, *viz.*, N.W.–S.E. As at Danta, they are associated with rhyolites and Idar granite but no dellenites occur. The rhyolites occur on the southern continuation of the general N.–S. line along which lie the Ora rhyolites and the rhyolites and dellenites of Pamta Hill.

Mineralogically similar to the Danta porphyries.

The following brief description of certain specimens from this area will indicate their mineralogical similarity to the porphyries of Danta and Sindret with which they are contiguous.

Composition of felspars.

Measurements by the Federov stage of the composition of four felspar individuals, twinned according to the Carlsbad and albite laws, in a felspar-porphyry (36/157, 17135) from two miles S. S. E. of Undwaria give the relatively acidic composition of 2 per cent. An.[1] A fair amount of epidote occurs in certain of the felspar phenocrysts. This, combined with the low anorthite percentage, would suggest that the felspars were originally more basic than at present. The specimen contains abundant chalcedony and also shows myrmekitic rims of various kinds (*see* pp. 119-120) around the periphery of certain orthoclase crystals.

Chalcedony.

Chalcedony was noted in a specimen (36/143, 17124) from half a mile north-west of the small village of Adli. Its masses are mostly aggregated around the edges of corroded quartz phenocrysts and to a lesser extent around orthoclase and even plagioclase crystals. The fine-grained groundmass contains a certain amount of chalcedony but is mostly felspathic material and quartz. A specimen (36/142, 17123) from near the above locality possesses remarkably corroded phenocrysts of quartz and felspar.

Chalcedony is abundant as rims round quartz crystals in a specimen (36/134, 17115) from half a mile south of Karara; but it also occurs as a rim around graphic aggregates of quartz and orthoclase. This section (17115) shows some remarkable structures. In certain cases, orthoclase crystals, with perthitic intergrowths of ? albite felspar, associated with quartz crystals, are surrounded by graphic

[1] If the individuals be Nos. 1 to 4, then Nos. 1 and 2 are twinned according to the Carlsbad law and Nos. 3 and 4 likewise; but No. 2 stands in the position of albite twinning with No. 3 and No. 1 stands in the same relationship to No. 4. Thus Nos. 1 and 3 stand in the position of the complex albite-Carlsbad with respect to each other as also do Nos. 2 and 4. A study of the symmetry of the individuals projected ⊥ [001] will make this clear.

intergrowths of quartz and orthoclase and the whole encircled by a glassy, merging into a ? chalcedonic rim. It would appear that after the formation of the rock with its original quartz and orthoclase (with perthite) phenocrysts, set in a fine-grained groundmass, there was resolution of both orthoclase and quartz and part of the groundmass; on recrystallisation, the solute was deposited as a graphic intergrowth in eutectic proportions. Conditions were later favourable to the deposition of chalcedony, the silica being derived either from the rock itself or from infiltrated siliceous solutions.

Composite felspars.

The groundmass of a specimen (36/136, 17117) from 1¾ miles north-east of Sanwara is largely chalcedonised. The slide shows a fair amount of calcite. Large composite felspar phenocrysts were noted in specimens from three miles west of Isri (36/135, 17116) and three-quarters of a mile north-west of Adli (36/144, 17125). The former specimen contains abundant hornblende. The orthoclase phenocrysts in a porphyry (36/129, 17111) from 2½ miles east of Mera contain abundant coarse perthitic intergrowths of acidic plagioclase felspar.

Idar granite grades into porphyries.

A porphyry (36/139, 17120) from three-quarters of a mile E. N. E. of Undwaria possesses abundant remarkable fine-grained graphic intergrowths of quartz and felspar. The regularity and intricacy of certain of these intergrowths gives designs of intrinsic beauty. Most of the granite occurring north-east of Undwaria is porphyritic in nature; some of it is best termed a porphyry as, *e.g.*, a specimen (36/141, 17122) from 2½ miles north-east of the village.

Microgranites.

The specific gravity of a specimen (36/137, 17118) from half a mile north of Undwaria is 2·59. This rock resembles a specimen (21219) from near Karara, both being more microgranites than porphyries. As will be seen later, rocks of this nature are common in other parts of the State.

Other Occurrences on Sheet 95.

Strike.

There are numerous occurrences of porphyry rocks on sheet 95 apart from those cropping out in the vicinity of Danta and Sindret. Most of them have a general N.–S. trend, at times, however, rather more N.N.E.–S.S.W. The strike of these rocks makes a small angle with the general N.N.E.–S.S.W. foliation of the Aravallis. It is totally different

from the strike of the Danta and the Undwaria porphyries which, as noted previously, varies from 110° to 135° (W. N. W.–E. S. E. to N. W.–S. E.).

The characteristic Malani hypabyssal rock on sheet 95 varies from a microgranite to a granite-porphyry. True felspar-porphyries and quartz-porphyries occur as well but they are not so common as microgranites.

Commonest types.

The porphyritic Idar granites of the Siloi area are accompanied by hypabyssal rocks finer in grain. The irregular though sharp nature of the junction between one of these quartz-porphyries (42/269, 21176) and the Erinpura granite which it intrudes two miles S. S. W. of the village is shown in figure 2 on Plate 3. The chilled margin of this porphyry (42/276, 21183) is much finer-grained than the main rock. What appear to be large fibres of chalcedony are developed around a quartz crystal in a section of the chilled edge of a porphyry (42/280, 21188) from 1¼ miles in the same direction from the village; this mineral can be seen in the groundmass.

Siloi.

Chalcedony is developed in these Siloi rocks in the same forms already noted for the Danta and Undwaria porphyries. Thus rims of that mineral surround quartz and felspar phenocrysts in a porphyry from three-quarters of a mile west of Dodia (north of Siloi). Again beautiful and intricate micrographic intergrowths of quartz and orthoclase are conspicuously developed in porphyries from just west (42/268, 21175), and from three-quarters of a mile south-west of Siloi (42/273, 21180); the former contains abundant biotite.

Composite felspar phenocrysts and groundmasses with graphic structure were noticed in sections of porphyries from localities to the north and south of Siloi, *viz.*, 1½ miles south-west of Pardi (42/286, 21195); and 1½ miles N. N. E. of Bilangri (42/270, 21177).

As a rule these porphyries contain but few ferromagnesian minerals except those due to alteration (chlorite, epidote, etc.). Biotite does occasionally occur in the coarser-grained varieties; hornblende is also found in very small prisms or microlites (42/272, 21179). It is at times exceedingly difficult to state with certainty whether the very fine-grained ferromagnesian material is hornblende or biotite.

A chloritic mica was noted in a porphyry (42/265, 21171) from three miles north-east of Kalandari. Abundant light greenish-brown biotite occurs in a porphyry (42/268, 21175) from just west of Siloi and in another (42/223, 21125) from just south-east of Kuma. A

specimen (42/259, 21165) from 1½ miles north of Sarthara shows very dark reddish-brown biotite.

Mention has already been made of the felspar-porphyry dyke one mile N. N. E. of Bilangri (*see* p. 99) which intrudes, and contains fragments of, basaltic dykes (21221) which themselves intrude Erinpura granite.

Bilnagri.

The felspar-porphyry (42/306, 21222), as will be seen from figure 1 of Plate 2, also intrudes the Erinpura granite. A section (21220) of the junction between these shows the narrowness of the chilled margin of the porphyry.

Porphyry dykes are common in the area south-east, south and south-west of Siankra, cutting Aravalli schists and Erinpura granite.

Siankra.

Typical specimens from three miles S. S. E. of Siankra (42/220, 21122) and 2½ miles E. S. E. (42/222, 21124) and half a mile S. S. W. (42/217, 21118) of the same village show corroded phenocrysts of quartz and felspar, set in a chalcedonic and micrographic groundmass. These porphyries are rather more acidic than those previously described, containing as a rule more and larger phenocrysts of quartz than of felspar, and few ferromagnesian minerals. South-west of Siankra, they grade into extremely quartzose rocks recalling the reef-quartz pegmatites of the Erinpura granite, than which, of course, they are much younger. They also grade into normal granite- and felspar-porphyries, to which they have been similarly coloured on the one-inch sheets. The quartzose rocks are very brecciated as, *e.g.*, in a specimen (42/201, 21100) from two miles S. S. E. of Sanpura, an adjacent village. They occur in Erinpura granite, cutting it and the pre-Malani basic dykes which also intrude the granite. A diagrammatic sketch of the relations of the southward continuation of the quartz porphyry dyke (42/202, 21101) cutting the granite of hill station 1,287 feet has already been given (*see* Fig. 7, p. 97). There seems but little doubt that these Siankra porphyries were derived from an acidic differentiate of the cooling magma which gave rise to the Idar granite.

Accessory minerals are not common in all the above-described porphyries of sheet 95. Iron-ore occurs but is not very abundant.

Accessories.

Apatite is rare. Sphene was noted in a specimen (42/273, 21180) from three-quarters of a mile south-west of Siloi. Most accessory minerals were noted in those porphyries with composite felspar phenocrysts.

Other Occurrences on Sheet 96.

Dantrai.

In the extreme north-western corner of the sheet, a small series of porphyries, somewhat reminiscent of the occurrences at Danta and Undwaria, are associated with the porphyritic Idar granite of Nandwar Hill, of which they are the hypabyssal equivalent. These porphyries resemble the others mineralogically. Thus specimens from three miles W. N. W. of Dantrai (42/197, 21094) and from Harni (42/198, 21095) contain large pink crystals of orthoclase felspar with small ones of quartz set in a fine-grained groundmass, at times micrographic and chalcedonic.

Uchmat.

A porphyry (42/207, 21107) from half a mile south of Uchmat in Jodhpur (sheet 75), which is related to the Dantrai series, contains abundant biotite.

Sanwara.

An approximately N.–S. trending series of dykes crops out in the neighbourhood of the villages of Sanwara and Sirori. Specimens from Sanwara village (20897) and from half a mile north of it (20898; 42/315, 21231) contain sufficient large flakes of biotite to warrant these rocks being termed granite-porphyries.

Songali.

Porphyries from one mile north-east of the small village of Songali (17623) and three-quarters of a mile in the same direction (36/813, 17624) show resemblances to the Undwaria series to the north. There are many small intrusive dykes in this vicinity cutting the Aravalli phyllites.

Pegmatite accompanying the Idar Granite.

Scarcity of pegmatite.

One of the most characteristic differences between the Idar and Erinpura granites is the great amount of pegmatite which accompanied the latter, whilst the Idar granite was conspicuously free from such acidic differentiation products. This may be accounted for by the following considerations. Firstly, whilst the parent reservoir supplying the magmas responsible for the formation of the various intrusive masses of Idar granite and its associated extrusive rocks was undoubtedly large, yet its size must have been much smaller than that of the reservoir responsible for the Erinpura granite. Thus given similar conditions of crystallisation which allowed differentiation to take place, one would expect the amount of pegmatite accom-

panying the Erinpura granite to be larger than that accompanying the Idar granite.

Secondly, the Erinpura granite undoubtedly crystallised out very slowly from its magma under a thick superincumbent layer of sediments, Aravallis and Delhis. The Idar magma was not so deep-seated, and great quantities of the probably already slightly acidic upper portion reached the surface in the form of extrusive lavas, whilst large amounts escaped along the tensional cracks formed during its cooling. The remnants of the magma under the congealed mass of lavas cooled more quickly than did the Erinpura granite. Accordingly it is not to be wondered at that the Idar granite is far freer from pegmatite than its predecessor.

The pegmatite associated with the Idar granite is in the form of quartz-veins, sometimes a few inches in thickness but generally much narrower. It is only very exceptionally indeed that the size of these quartz-veins approaches that of the reef-quartz pegmatites which accompanied the Erinpura granite. The largest such example was noted at the northern end of hill station 1,055 feet, one mile W. S. W. of Angor (sheet 95). Ramifying veins from this mass penetrate the pink granite forming the main mass of the hill.

Quartz-veins.

Small veins of white reef-quartz were noted frequently in Malani porphyries but it was very seldom that these veins penetrated the basement Aravalli phyllites or schists.

Middlemiss has noted the possibility of certain reef-quartz veins in Idar State being the ultra-acidic differentiation product of the Idar granite,[1] and Dr. A. M. Heron has described very large reefs of quartz in the Idar granite near Raona and Pipar in Jodhpur.[2]

[1] *Mem. Geol. Surv. Ind.*, XLIV, p. 131, (1921).
[2] *Rec. Geol. Surv. Ind.*, LXV, Pt. 4, p. 470, (1932).

CHAPTER X.

MALANI SYSTEM—*concluded.*

VOLCANIC ROCKS: RHYOLITES AND DELLENITES.

Localities. Volcanic rocks of Malani age occur in Sirohi State in the following areas:—

1. Jharoli-Ban area (sheet 94).
2. Ora-Pardi area (sheets 94 and 95).
3. Pamta Hill, Sindret (sheet 95).
4. Mirpur-Undwaria area (sheets 95 and 96).

Jharoli-Ban Area (Sheet 94).

Occurrence. A brief description of the rhyolites of this area is given in the General Report of the Geological Survey of India for 1926.[1] They were mapped by Hacket and wrongly coloured as Aravallis by La Touche in his map of Western Rajputana.[2] There is no doubt that these rhyolites, associated with a granite corresponding in age to the Jalor and Siwana granites of La Touche, are similar in age to the Malani rhyolites of Western Rajputana. They overlie Aravalli shales and slates 1½ miles north-west of the village of Mosal. They are not seen in actual contact with the Idar granite of Ban in this region, being separated from it by a rock best termed a granite-porphyry, which represents a chilled border facies of the Ban granite. There is, however, but little difference in age between the granite and the rhyolites, the consanguinity of which is discussed later (*see* pp. 139-140).

Andor. A black rhyolitic tuff (36/54, 17022) appears to overlie the Idar granite forming the hill a little to the south of Andor. A thin section (17022) of this rock is inconclusive, but in the field, fragments of slates, reef-quartz, shales, etc., were seen in a fine-grained siliceous groundmass.

Contrast in weathering of granite and rhyolite. The contrast between the smooth rounded hills of granite and the rugged jointed hills of rhyolite has already been noted (p. 105).

[1] *Rec. Geol. Surv. Ind.*, LX, pp. 113-114, (1928).
[2] *Mem. Geol. Surv. Ind.*, XXXV, Pt. 1, Map, (1902).

The lavas possess the same general characteristics noted by La Touche.[1] Their colour varies from black to red, brown, green and even white. The predominant colours in the vicinity of Jharoli and Ban are dark-brown to red and are due to the presence of oxides of iron. Flow structure and banding are common, but perlitic textures are much rarer here than in the case of the Pamta Hill and Undwaria rhyolites. The rocks are extremely siliceous and in most cases the original glass has devitrified to an extremely fine-grained siliceous mass. Tuffs are not as common here as in the occurrences in other parts of the State. With one exception, no actual pipes or vents were noted in the Jharoli-Ban area; and it seems probable that the lavas here flowed to the north-west when the roof of Aravalli shales and slates overlying the intrusive Idar granite[2] gave way in consequence of the pressure accompanying, or caused by, the intrusion. However, a very agglomeratic facies was noted in the hills four miles west of Jogipura. It is probable that this is on the site of a subsidiary pipe or vent where the extrusion of the lavas was violent in nature. As will be seen later (*see* pp. 139-140), it is believed that the Ora-Pardi rhyolites were extruded from an independent vent, trending N.–S., south-west of the Ban granitic *massif*.

Tuffs and agglomerates rare.

The analysis by Mons. F. Raoult of a specimen (36/65, 17033) from three miles W. N. W. of Alpa has been given in Table VII (p. 117), together with Osann's average of 64 liparites, including 40 rhyolites for purposes of comparison. A study of the figures in that table will show that the Alpa rhyolite is slightly more acidic than the average rhyolite. Mr. L. R. Sharma, however, determined the silica percentage in a black rhyolite (36/57, 17025) from half a mile south of Talaita as 71·35. The percentages of the remaining constituent oxides are very comparable.

Analyses.

The specific gravities of the Alpa specimen and of a rhyolite (36/58, 17027) from two miles S. S. E. of Talaita are 2·617 and 2·64 respectively, which values agree with La Touche's results.[3]

Specific gravities.

[1] *Op. cit.*, pp. 20-24.
[2] The centre of the main granitic mass probably lies to the east of Ban, but it is impossible to state this with certainty.
[3] *Op. cit.*, p. 79.

The analysed specimen (36/65, 17033) shows crystals of quartz, orthoclase and acidic plagioclase set in a fine-grained groundmass composed of quartz, chalcedony, felspathic material and a little calcite which is the result of the devitrification of the original siliceous glass. A little chlorite was noted. The spherules of chalcedony (*see* also 36/59, 17026) between crossed nicols show a cross which is parallel to the cross-wires and rotates with the rotation of the nicols.[1]

Minerals present.

The fibres constituting the spherules generally have their elongation parallel to $\mathfrak{a}$, the fastest ray. If the fibres were quartz, elongated parallel to the *c* axis, this ray would always be the slowest. The felspars show kaolinisation and sericitisation. A rough banding is visible in the section.

Corrosion of quartz and felspar crystals may be seen in the section (17027) of the specimen (36/58) from two miles south-east of Talaita. La Touche noted that whilst quartz phenocrysts were frequently corroded, the felspars as a rule did not show corrosion.[2]

Corrosion of phenocrysts.

The corrosion of felspars in felspar-porphyries, with the formation of a myrmekitic intergrowth of quartz and orthoclase, has already been noted (*see* p. 119). Corrosion of felspar phenocrysts was quite commonly noted (17027; 17032) in the Jharoli-Ban rhyolites. The number of phenocrysts varies largely but they are commonly plentiful, though not as plentiful as in the rhyolites of the Pamta Hill. A rhyolite (36/66, 17034) from 2½ miles W. N. W. of Alpa showed very few.

Inclusions of shales and other Aravalli rocks were commonly noticed in the rhyolites of the Jharoli-Ban area. Specimens from half a mile south of Talaita (36/57, 17025), from 2½ miles S. S. W. of the same village (36/59, 17026), from one mile north of Las (36/62, 17030), and from 2½ miles E. N. E. of Jharoli (17032) show these under the microscope.

Inclusions.

No dellenites.

No equivalents of the dellenites of Pamta Hill occur in the Jharoli-Ban area.

[1] *See* previous notes for the hypabyssal rocks (pp. 120-121). Also O. Mügge, 'Rosenbusch's Mikroskopische Physiographie der petrographische wichtigen Mineralien', Stuttgart, I, Pt. 2, p. 196, (1927); and T. H. D. La Touche, *op. cit.*, p. 87.

[2] *Op. cit.*, pp. 79-82.

Ora-Pardi Area (Sheets 94 and 95).

The rhyolites forming the hills in the vicinity of Ora (sheet 94) are largely chloritised and consequently have a distinctly greenish colour. A specimen (36/56, 17024) from one mile south of the village shows abundant corroded phenocrysts of quartz, with fewer of plagioclase and orthoclase, set in a finely crystalline groundmass, scattered through which are flakes of varying size of a chloritic mineral. This specimen is less altered than those from near the village.

Characteristic greenish colour.

There are several isolated hills of greater or lesser size almost due south of the Ora rhyolites and lying along the same general north and south line. The largest of these hills is the peak, 990 feet in elevation, 3½ miles north-east of Pardi (sheet 95). The rock forming this hill (42/281, 21189) has a specific gravity of 2·69 and contains abundant corroded quartz crystals and inclusions of shales. The predominant colour of these rhyolites is green.

Occurrences near Pardi.

The rhyolites of Ora and Pardi bear more resemblance to the rhyolites of Pamta Hill than to those of the Jharoli-Ban area. They lie along the same general north and south line and were extruded in fissures formed at the same time as those responsible for the rhyolites of Pamta Hill. Volcanic activity, however, ceased in the Ora-Pardi area before it did in the Pamta region, there being no representatives of the later dellenites so common in that region and of the felspar-porphyries of its vicinity.

Resemblance to Pamta Hill rhyolites.

Pamta Hill, Sindret (Sheet 95).

A reference to the geological sketch map of the area (*see* Fig. 9 on p. 116) will show that Pamta Hill is composed chiefly of rhyolites and dellenites. Part of the northern extension of the hill has been omitted from Figure 9 for reasons of limitation of space; this northern part may be seen on the smaller scale map forming Plate 12 of this memoir.

Sketch map.

The rhyolites occur mainly at the southern and northern extremities of the hill. They appear to have been the first phase of volcanic activity, the more basic dellenites overlying them in such sections as are visible in the field.

Rhyolites.

Petrological notes.

The Pamta rhyolites are generally green in colour, in strong contrast to the general reddish tints of the dellenites. Those near Varela show pillow or spheroidal weathering and appear to overlie Aravalli rocks unconformably. In the northern part of the range, west of Khomal, they weather so as to appear at a first glance like conglomerates. They thus resemble the nodular rhyolites on the southern slopes of Mynydd-y-Gader in Wales.[1] These nodular rhyolites form steep hills, whereas the usual varieties found in the southern part of the hill form more rounded hills.

Mica.

A specimen of the spheroidally weathering rhyolite from the deserted village of Varela (36/124, 17105) contains abundant quartz and sericitised orthoclase crystals in a devitrified groundmass. The rock is especially interesting in containing large flakes of a mica, weakly pleochroic from light greenish blue to colourless, with abundant iron-ore inclusions, and also composite masses of ? iron-ore. The mica does not appear to be secondary in nature. It is interesting to note that La Touche found brown mica in a tuff (11/500) from Jodhpur State and stated that this was the sole instance in which he found this mineral associated with any of the Malani rhyolites.[2]

Varying types of rhyolites.

A specimen (36/123, 17104) from half a mile south of the same village (Varela) appears in the field to be a type more or less intermediate in character between a granite and a rhyolite; this is borne out by the thin section. Another (36/122, 17103) from half a mile north of the village has the nature of a pumice or vesicular rhyolite. An adjacent specimen (36/125, 17106) contains very abundant quartz phenocrysts, with few of orthoclase, set in a very fine-grained devitrified groundmass. A devitrified rhyolite (36/121, 17102) from 1½ miles south-west of Sindret, which is intruded by a porphyry (36/120, 17101) regarded as probably being one plug from which the dellenites were extruded, is of normal type but with a coarser-grained groundmass than usual. It resembles a specimen (36/100, 17079) from an outlier, half a mile south-west of the village.

Nodular rhyolites.

Nodular rhyolites were collected in the northern part of the Pamta Hill from the summit of hill station 1,295 feet, 1¼ miles north-west of Khomal (42/291-293, 21199-21201); three-quarters of a mile W. N. W. (42/296,

[1] P. Lake and S. H. Reynolds, *Q. J. G. S.*, LXVIII, pp. 359-360, (1912).
[2] *Mem. Geol. Surv. Ind.*, XXXV, p. 89, (1902).

21204); one mile west (42/298, 21206); and the same distance south-west of the village (42/299, 21208). The specific gravities of 42/292 and 42/293 were 2·65 and 2·64 respectively. Examination under the microscope shows many traces of perlitic structure, partly obliterated by the processes of devitrification and alteration. One specimen (42/292, 21200) shows abundant secondary calcite and a fair number of felspar phenocrysts. Another (42/293, 21201) contains a moderate quantity of a dark red-brown mica, some of which at least appears to be primary; a third (42/296, 21204) contains possible inclusions of shale. The phenocrysts of orthoclase and quartz were in most cases very corroded. The specimens appeared distinctly conglomeratic in the field.

Dellenites.

Reference may again be made to Figure 9 on page 116 which shows the distribution of the dellenites which overlie the rhyolites. They also unconformably overlie the basal Aravalli shales and contemporaneous volcanics of this neighbourhood, the basal rock of the dellenites in these cases usually weathering in a characteristically rounded fashion. Apart from these basal members, the dellenites usually weather angularly to form steep-sided hills. The peaks of 2,063 feet and 1,961 feet stand some 900 feet higher than the general elevation of the surrounding country.

Composition of felspars.

It will be remembered that the plagioclase felspars of the porphyries usually have a composition of about 33 per cent. An, though more acidic plagioclase is found. The following brief description of some results obtained by the Federov stage will indicate the similar composition of the plagioclase in the dellenites.

An albite-Ala B complex in a specimen (36/99, 17078; specific gravity, 2·64) from one mile W. S. W. of Sindret has a composition of 33 per cent. An.[1] Another specimen (36/119, 17100), collected from the top of hill station 1,961 feet, west of Sindret, contains two individuals of compositions 33 and 42 per cent. An, which are in the position of the complex albite-Ala B. The second individual contains a few pericline lamellæ too small for the determination of their composition.[2] This complex is adjacent to an albite-pericline combination, all the individuals of which have a composition of 33 per cent. An. A third specimen (36/115, 17096) from the top of

[1] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, pp. 173, 181, (1931).
[2] A. L. Coulson, *op. cit.*, p. 167.

Pamta Hill, 1½ miles north-west of Sindret, contains an albite-Ala B complex with individuals of composition 33 per cent. An.[1] As has been suggested elsewhere by the author,[2] 30-35 per cent. An appears to be favourable for the formation of the complex albite-Ala B, at least in volcanic and hypabyssal rocks, though it is not suggested that albite-Ala B complexes of this and other compositions are restricted to volcanic and hypabyssal rocks.

Analysis.

An analysis by Mons. F. Raoult of a dellenite (36/119, 17100; specific gravity, 2·642) from the top of hill station 1,961 feet west of Sindret, has been given in Table VII on page 117. The name dellenite is synonymous with the names quartz-trachy-andesite and quartz-latite.[3] The term toscanite has been used by Washington for a variety of quartz-trachy-andesite.[4] It will be seen from a comparison of the figures in Table VII that the Sindret specimen closely resembles in composition the quartz-trachy-andesite from Porobbo, Toba Lake, Sumatra, analysed by Herz, and also the quartz-felspar-porphyry from one mile north of Danta, Sirohi State, analysed by Mons. F. Raoult.[5] These all are distinctly more basic than the rhyolite from three miles W. N. W. of Alpa which cannot differ largely in composition from the rhyolites of Pamta Hill.

Minerals present.

The following brief description of the mineralogical characters of certain specimens gives added weight to the designation of these rocks as dellenites (or quartz-trachy-andesites).

Spheroidally weathering dellenites.

The spheroidally weathering dellenites found at the base of the hill and overlying the Aravalli rocks show the effects of palagonitisation and other alteration processes. They also appear to be partly tuffaceous in nature. Thus a specimen (36/109, 17088) from 1¼ miles south-west of Khomal contains abundant angular and corroded fragments of quartz with less frequent orthoclase and plagioclase crystals, set in a groundmass consisting of fine-grained silica and palagonitisation

[1] A. L. Coulson, *op. cit.*, Fig. 3 and the full description on pp. 179-180.

[2] *Op. cit.*, p. 183.

[3] A. Holmes, 'The Nomenclature of Petrology', London, p. 76, (1920).
The name dellenite is in common use in Paris and other continental cities where the petrological characters of these rocks were studied. It has been used in the author's previous papers and accordingly, to avoid confusion, it has been decided not to alter it to the more common quartz-trachy-andesite.

[4] A. Holmes, *op. cit.*, p. 227.

[5] Useful comparison may also be made with the two analyses of toscanites from the Lilydale Devonian series of Victoria given by H. S. Summers, *Proc. Roy. Soc. Vict.*, XXVI, (N. S.), p. 284, (1914).

products, mostly ? delessite and calcite. Relics of spheroidal structure can be seen in the section. Sphene is fairly abundant. A near-by specimen (36/111, 17090) also contains several idiomorphic sphenes and a small ? zircon crystal. There is possibly a small amount of bluish celadonite[1] in this section. A third specimen (36/116, 17097) from one mile north-west of Sindret contains a little apatite. A fourth (42/300, 21209; specific gravity, 2·66) from 1½ miles south-west of Khomal resembles the specimens previously described and also contains a peculiar dark-brown to black mineral of doubtful optical character.

Basal dellenite overlying rhyolites.

A specimen (42/297, 21205) from three-quarters of a mile W. N. W. of Khomal was taken from the base of the dellenites where they overlie and metamorphose the lower rhyolites (42/296, 21204). This contains abundant orthoclase and quartz set in a reddish glass, not yet totally devitrified. Another basal specimen (36/117, 17098) was collected from half a mile west of Sindret.

Upper dellenites.

The normal upper dellenites (36/99, 17078; 36/107, 17086; 36/115, 17096; 36/119, 17100; 42/294, 21202) typically contain phenocrysts of quartz, orthoclase, at times microperthitic, and plagioclase of approximately 33 per cent. An, all occasionally corroded, set in a devitrified groundmass. The original ferromagnesian mineral was almost certainly hornblende, but it is generally completely altered to chloritic products and epidotic and zoisitic minerals. The felspars are kaolinised and sericitised and it is possible that the plagioclases were in some cases more basic than at present. Secondary calcite is common.[2] Iron-ore is a frequent accessory; less common are apatite (17086; 17096), sphene (17100) and zircon (17100).

Specific gravity.

The specific gravity of the dellenites varies from 2·60 (42/294) to 2·71 (36/107). The average specific gravity of six specimens is 2·66.

Mirpur-Undwaria Area (Sheets 95 and 96).

Rhyolites.

Rhyolites are the sole volcanic rocks found in this area. They resemble those of Pamta Hill and the Ora-Pardi area more than the rhyolites of the Jharoli-Ban area. The main occurrence lies to the south of, and

[1] L. L. Fermor *Rec. Geol. Surv. Ind.*, LVIII, p. 144, (1926).
[2] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXV, p. 183, (1931).

along, the same general line as the two first occurrences. It stretches southwards from one mile south of Mirpur (sheet 95) to 1¾ miles E. N. E. of Undwaria (sheet 96), a total distance of some 3½ miles. Its usual width is about half a mile. Other isolated occurrences lie 2½ miles N. N. E., 1½ miles north-east, 1¼ miles south-east, and 2½ miles S. S. E. of Undwaria; and half a mile north-west of Adli.

Petrological notes.

Specimens (36/112-114, 17112-17114) from two miles east of Mera, in the chief occurrence mentioned above, show relics of a spherulitic structure in a totally devitrified fine-grained groundmass. Fragments of shale and flow structure are common (17113) and certain specimens are distinctly tuffaceous (17114). The number of quartz and orthoclase phenocrysts varies; they are frequently corroded. The isolated outcrop some 2½ miles N. N. E. of Undwaria is also distinctly tuffaceous (36/140, 17121). The small outcrop 1¼ miles south-east of the last village is composed of a rhyolite (36/154, 17132) showing flow structure around corroded crystals of quartz and felspar.

The Interrelationship between the Malani Rocks of Sirohi State and their Correlation with Representatives in other Areas.

Variation diagram.

In Figure 10, which follows, the percentages of the constituent oxides of the following rocks, analyses of which by Mons. F. Raoult have been given in Table VII (*see* p. 117), have been plotted as ordinates against the respective silica percentages as abscissæ:—

36/97. Quartz-felspar-porphyry, one mile north-west of Danta (sheet 95).

36/119. Dellenite, top of hill station 1,961 feet, one mile north-west of Sindret.

36/128. Potash-granite, foot of hill station 2,181 feet, one mile south-east of Mirpur (sheet 95).

36/65. Banded rhyolite, three miles W. N. W. of Alpa (sheet 94).

36/60. Potash-granite, Ban (sheet 94).

The alumina percentage plotted is the actual figure *less* 8 per cent. The plotted Fe O percentage represents the total iron content calculated as that oxide.

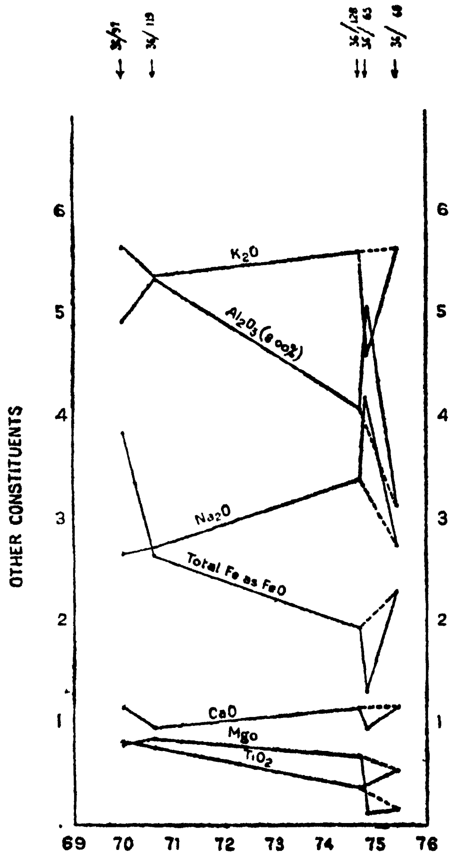

FIG. 10.—Variation diagram, showing the variation in the percentages of the constituent oxides of the Malani rocks of Sirohi State.

Conclusions from variation diagram.

It will be seen that if a mean figure be taken for the percentages of the constituent oxides in the Mirpur potash-granite and the Alpa rhyolite, the resultant variation diagram will show much less discordance than that illustrated in Figure 10. The silica percentages of these rocks are so nearly alike that steep variation lines must result through any difference in percentage of the constituent oxides. If,

alternatively one omits entirely the results of the analysis of the rhyolite and, as has been done in Figure 10, joins the percentages of the constituent oxides of the Mirpur potash-granite with dotted lines directly to those of the Ban potash-granite, the variation lines flatten out remarkably well and the relationship between these Malani rocks can clearly be seen.

The only other analysis of a Malani rock is that by the author's colleague, Dr. W. A. K. Christie, of the Kawa hornblende-granite from Idar State already cited in Table VI (*see* p. 107). This is more basic than any of the Sirohi rocks, but by extending the variation diagram in Figure 10, it was found that there is also a distinct relationship between this type Idar rock and the Sirohi representatives.

It is considered that the Nandwar, Ban and Isri plutonic masses were intruded at the same time as the Idar granite in Idar State and the Idar (Jalor and Siwana) granites in Jodhpur. The intrusion in Sirohi State appears generally to have been accompanied by, or alternatively was a consequence of, considerable earth movements. The Ban *massif* was more probably quietly intruded, gently stoping its way through the superincumbent strata, which at last, however, gave way with the resultant outpouring of the Jharoli-Ban rhyolites to the north-west and north. Probably a subsidiary, N.–S. fissure, running north from the main mass of granitic magma, was formed at the same time. The outlets were soon choked by the congealing lavas and the granitic magma cooled slowly.

Intrusion of granite and extrusion of volcanic rocks.

Meanwhile the Isri granitic magma had found a relatively easy path chiefly at or near the junction of the Aravallis with the Erinpura granite forming the Abu *massif*. This junction had almost certainly been a plane of movement at the time of the earth movements which accompanied the intrusion of the Erinpura granite (*see* p. 75). The Isri magma stoped its way quietly into both Erinpura granite and Aravallis, but later movement occurred, mostly along or parallel to the old junction line of these rocks, which is approximately N.–S. in these parts, with the resultant outpouring of the Ora-Pardi. Pamta Hill and Mirpur-Undwaria rhyolitic lavas.

Considering the granitic magmas which on cooling formed the granites of Nandwar Hill and the Sunda hills, there is an absence of any evidence denoting movement *at the same time* as the formation of the Jharoli-Ban rhyolites or of those in the Ora-Pardi, Pamta Hill and Mirpur-Undwaria areas.

It is necessary, however, to postulate the formation of another series of vents or cracks later than those responsible for the extrusion of the rhyolitic lavas. These later cracks were no doubt tensional, formed as a consequence of the strains set up by the cooling of the magmas which now form the Isri, Nandwar Hill and the Sunda hills outcrops of Idar granite. As a rule they trend N.N.E.–S.S.W., making a small angle with the general direction of foliation of the Aravallis and the direction of the rhyolitic vents. The cracks were filled with material which, on cooling, gave rise to the porphyritic granites and the various porphyries on sheets 95 and 96. Near Danta, which is near the main mass of the Isri magma, the general direction of the porphyries filling the cracks is 110°–290° (W.N.W.–E.S.E.). Near Undwaria, which is likewise near the Isri magma, the direction is N.W.–S.E.

Formation of hypabyssal rocks.

It is highly improbable, however, that the material which filled these cracks ever reached the surface. This point is also brought out by Middlemiss writing of the Idar porphyry :—[1]

'As the very similar granites of Siwana and Jalor are considered by La Touche to be generally equivalent in age to a large portion of the Malani rhyolite series it may well be that the quartz-porphyries of Idar are a petrological connecting link between a granite of the Idar, Siwana and Jalor types and the bedded Malani rhyolite flows. I do not mean that the Idar porphyry was the actual vent rock of the rhyolites as now exposed in Western Rajputana, but that they constitute vents of a similar related material that further north became extrusive as the acid Malani flows.'

Reference has been made (p. 103) to the widespread occurrence of rocks of Malani age. Blanford gave the name 'Malani beds' to the volcanic rocks in the district of Jodhpur bearing that name.[2] Hacket[3] described certain exposures and McMahon[4] compared the Malanis with the felsites of Tusham Hill in the Hissar district of the Punjab,[5] which seem to be the most easterly exposures of Malani rocks. La Touche[6] noted that Malani lavas extend at intervals for 145 miles west from Jodhpur, and from Pokaran in the north to Jalor in the south, a distance of 120 miles.

Distribution of Malani rocks.

[1] *Mem. Geol. Surv. Ind.*, XLIV, p. 129, (1921). *See* also *Rec. Geol. Surv. Ind.*, LXV, p. 144, (1932).
[2] W. T. Blanford, *Rec. Geol. Surv. Ind.*, X, p. 17, (1877).
[3] C. A. Hacket, *ibid.*, XIV, p. 302, (1881).
[4] *Rec. Geol. Surv. Ind.*, XIX, p. 161, (1886). R. D. Oldham, *ibid.*, p. 124.
[5] *Ibid.*, XVII, p. 108, (1884).
[6] *Mem. Geol. Surv. Ind.*, XXXV, pp. 21-22, (1902).

The present author's work has extended the southern limit of these volcanics to Undwaria (sheet 96) in Sirohi; whilst in the field season 1930-31, Dr. A. M. Heron[1] found rhyolites and tuffs at Biramsar and Randisar in Bikaner, and at Lodsar and Taonra in Jodhpur, which lie between Tusham Hill and the northernmost exposures (near Pokaran) noted by La Touche. The Jhunjhunu exposures of Western Jaipur noted by Dr. Heron[2] elsewhere lie in a similar position. There are no outcrops between the Malanis of Tusham Hill and those of Kirana[3] further north.

The plutonic representatives of the Malanis were first noted by La Touche[4] at Jalor and Siwana in Jodhpur. Middlemiss' Idar granite,[5] which name includes the above granites, is developed in force, together with a few hypabyssal representatives, in Idar State and in Sirohi. During the field season 1930-31, Dr. Heron[6] recognized a variety of Idar granite (with topaz) at Rewat near Degana and three miles south-east of Lodsar in Jodhpur, and at hill station 1,238 feet, three miles east of Khuri in Bikaner.

Boulders of Malani granites and rhyolites have long since been known in the Salt Range Boulder Bed.[7]

[1] *Rec. Geol. Surv. Ind.*, LXVI, p. 132, (1932).
[2] *Ibid.*, LIV, p. 343, (1923).
[3] A. M. Heron, *Rec. Geol. Surv. Ind.*, XLII, p. 234, (1913).
[4] *Mem. Geol. Surv. Ind.*, XXXV, pp. 24-25, (1902).
[5] *Mem. Geol. Surv. Ind.*, XLIV, p. 115, (1923).
[6] *Rec. Geol. Surv. Ind.*, LXVI, pp. 131-133, (1932). Also *see op. cit.*, XLIV, p. 26, (1914), and *op. cit.*, XLVII, p. 26, (1916).
[7] C. S. Middlemiss, *Rec. Geol. Surv. Ind.*, XXV, p. 29, (1892); E. Koken, *Neues Jahrb. f. Min.*, p. 454, (1907); F. R. C. Reed, G. de P. Cotter and H. M. Lahiri, *Rec. Geol. Surv. Ind.*, LXII, pp. 417-419, (1930). The Waloria granite referred to in the quoted note by the present author is now regarded by him as being a form of Erinpura granite and so is not of Malani age (*see* p. 66 of this memoir).

CHAPTER XI.

POST-MALANI BASIC ROCKS.

Altered Dolerites occurring in the South-Western Part of Sirohi.

The rocks described in this chapter belong to the last, or fourth, basic phase mentioned in the introductory discussion in Chapter II (*see* p. 14). Their chief occurrences are in the south-western corner of the State bordering Palanpur on sheet 97; they also occur in the north-eastern corner of sheet 77, the south-eastern corner of sheet 76, and the south-western corner of sheet 96. Figure 11 is a geological map of parts of these four sheets and shows the nature of the outcrops.

Locality.

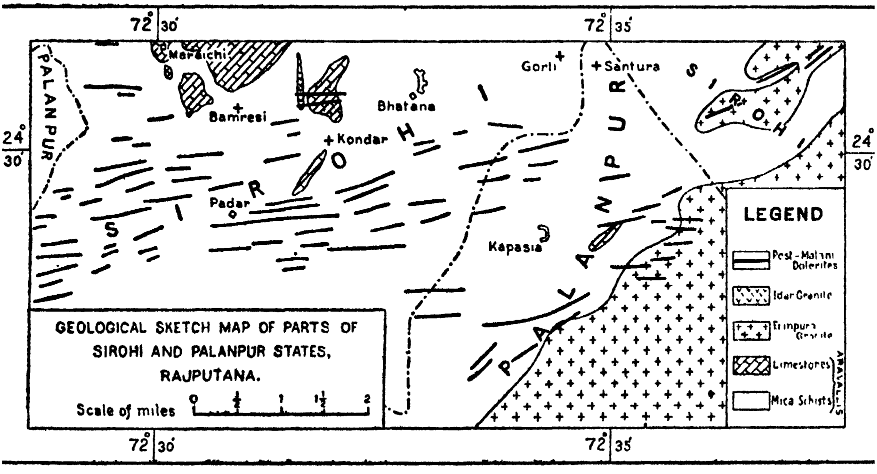

FIG. 11.—Geological map of parts of sheets 76, 77, 96 and 97, Sirohi and Palanpur States, showing the nature of the outcrops of post-Malani altered dolerites. The longitudes are those of the one-inch sheets.

The general strike of these rocks is approximately E.–W. and is at all times oblique to the N.N.E.–S.S.W. to N.E.–S.W. strike of the Aravalli rocks in this region. South of Kapasia, however, their general trend is more E.N.E.–W.S.W. They have a definitely greenish appearance and on weathering form a thin crust of half to three-quarters of an inch thick.

Strike.

These basic rocks cut Erinpura-granite pegmatite just east of Padar (sheet 97); they are found intrusive into the Erinpura granite forming the flanks of Chotila Hill (2,755 feet) east of Kapasia; and they cut the por-

Evidence of age.

phyritic Idar granite south of Dewari (sheet 96). Thus there is no question that they are younger than the Malani rocks described in the previous chapters (Chapters VIII to X). It is thought, however, that they are not *much* younger than these Malani rocks, as the E.–W. lines along which they occur are regarded as being related to the somewhat similar lines along which occur the felspar-porphyries of the Danta (sheet 95) and Undwaria (sheet 96) areas. In fact it is considered that the lines of weakness along which these basic rocks occur are allied to, and were probably formed at the same time as, the general E.–W. faults which have affected the granite-porphyries and porphyritic Idar granites of Malani age.

Minerals present.

A typical specimen (36/798, 17607 A and B) of these post-Malani basic rocks from S.S.W. of Bhatana (sheet 96) has a specific gravity of 2·66 and consists of laths of felspar with abundant biotite and a little iron-ore and secondary calcite and epidote.

Boricky's method.

Experiments were made by Boricky's method for the determination of the presence of sodium, calcium, potassium,[1] etc. by the shapes of the respective salts formed by these metals with hydrofluosilicic acid, in order to prove microchemically that the felspars were albitised. A small fragment of the rock (36/798) was ground up and cold dilute hydrochloric acid was added in order to dissolve the calcite (cold so as not to attack the felspars). This was left overnight and then thoroughly washed and dried. A few grains of the dried powder were placed on a glass slide covered with Canada balsam which had been cooked to the requisite hardness and a drop of hydrofluosilicic acid added. The slide was placed over water for a few minutes and then over sulphuric acid in a desiccator. When dry, the slide was examined with a microscope which had a glass cover-slip attached to the objective by means of a smear of glycerine (so as to protect the objective from the fumes of such hydrofluosilicic acid as remained). Practically the only crystals formed were cubes of potassium fluosilicate, chiefly with octahedral terminations.[2]

[1] Boricky, 'Elemente einer neuen chemisch-mikroskopischen Mineral-und Gesteinsuntersuchung', Prague, (1877).
A. Michel Lévy, 'Les Mineraux des Roches', Paris, I, pp. 124-125, (1888).
H. Rosenbusch and E. A. Wulfing, 'Mikroskopische Physiographie der Mineralien und Gesteine', Stuttgart, I, Pt. 1, pp. 435-447, (1904).
L. Cayeux, 'Étude pétrographique des roches sédimentaires', *Mémoires pour servir à l'explication de la Carte géologique détaillée de la France*, Parsi, pp. 118, 130-131, 136-137, 148-149, 157-160, (1916).

[2] *Cf.* Cayeux, *op. cit.*, pp. 130-131.

This method has been described in detail for the results were contrary to what was expected and it is difficult to account for them. One would conclude from the test that the felspars were not albitised, but this is contrary to the evidence of the thin section and also to the analysis of a similar rock given below.

Analysis.

The results of an analysis by Mons. F. Raoult of a specimen (36/799, 21329) from two miles south-west of Kapasia (Palanpur State) are given in Table VIII, together with the average of seven analyses of spilites[1] and Daly's average basalt.[2]

TABLE VIII

	36/799	A	B
	Per cent.	Per cent.	Per cent.
SiO_2	54·00	46·01	49·06
TiO_2	0·82	2·21	1·36
Al_2O_3	16·37	15·21	15·70
Fe_2O_3	1·67	1·35	5·38
FeO	6·23	8·69	6·37
MnO	0·10	0·33	0·31
MgO	1·58	4·18	6·17
CaO	5·18	8·64	8·95
Na_2O	4·51	4·97	3·11
K_2O	4·20	0·34	1·52
H_2O—105°C	0·06	..	..
H_2O+105°C	2·51	2·48	1·62
CO_2	2·81	4·98	..
P_2O_5	0·23	0·61	0·45
TOTALS	100·27	100·00	100·00
Specific gravity	2·702	..	..

36/799. Albitised dolerite, two miles south-west of Kapasia (sheet 97), Palanpur State, Rajputana (F. Raoult).

A. Average of seven analyses of spilites.

B. Average of 198 basaltic rocks.

[1] A. K. Wells, *Geol. Mag.*, LX, p. 69, (1923).

[2] R. A. Daly, 'Igneous Rocks and Their Origin,' New York, p. 27, (1914).

It will be seen from a study of the figures in Table VIII that there are certain resemblances between the Kapasia specimen and the average spilite. Wells states that the average spilite is distinctive in the following particulars:—very high percentages of titania, soda and carbon dioxide; very low percentages of magnesia and potash; state of oxidation of the iron.[1] The Kapasia specimen has low titania (0·82 compared with 2·21), high soda (4·51 against 4·97), and moderately high carbon dioxide (2·81 against 4·98); very low magnesia (1·58 compared with 4·18 in the spilite) but high potash (4·20 against 0·34); and the iron is mostly in the ferrous state.

Conclusions from analysis.

In spite of the results with Boricky's test, it appears that the Kapasia specimen, which is typical of the other post-Malani basic rocks in this region, has a strong alkaline character and bears many resemblances to the spilitic rocks. There is, however, no evidence whatsoever that these post-Malani basic rocks were submarine in nature; indeed all the evidence is to the contrary. They are best described as albitised basalts, it being clearly understood that the soda in these rocks is derived from the magma. It is unfortunate that no analyses of the other post-Malani basic rocks, described in the next section, are available for the purposes of comparison.

The following additional specimens were collected:—an albitised and chloritised dolerite (36/797, 17605) from one mile north of Kapasia, which contains a fair amount of iron-ore (efforts to measure the compositions of the felspars in this rock by Federov stage methods proved unavailing); a similar rock, but darker in colour (17606), from the same locality containing more iron-ore and abundant chlorite; an altered dolerite (21328) from one mile W.N.W. of the same village; and another (36/800, 21330) from one mile W.S.W. of Amlia (sheet 77).

Other specimens.

Other Post-Malani Basic Rocks.

During his inspection tour in Sirohi in March, 1930, Dr. A. M. Heron collected a specimen (20900) of a fine-grained basic dyke intruding the Malani granite-porphyry half a mile west of Sanwara village (sheet 96). This consists of a felted mass of laths of plagioclase felspar with abundant iron-

Sanwara.

[1] *Loc. cit.*

ore, the ferromagnesian minerals being entirely altered to chlorite with characteristically low polarisation colours. Calcite is present in fair amount.

Dr. Heron also noted a basic dyke (20902) in rhyolite or granite-porphyry on the river bank half a mile north of Mirpur (sheet 95). This rock is similar to the above specimen but is coarser in grain.

Mirpur.

Another definitely post-Malani basic (21213) was noted by the author intruding Idar granite (42/317, 21214) 1¼ miles east, a little south, of Mirpur. This also contains abundant plagioclase and iron-ore, with secondary calcite and a pale-green mineral with ultra-violet polarisation colours.

Basaltic dykes (42/282, 21190) were noted intruding the rhyolite occurring 3¾ miles north-east of Pardi (sheet 95). These are very decomposed in the hand specimen, but a relatively fresh piece shows abundant calcite and iron-ore. There is a large development of a pale-green to colourless mineral with circular polarisation which occurs also filling cavities in the rock.

Pardi.

Several altered basalts (36/85, 17065) were noted 3¼ miles south of Danta (sheet 95) cutting Idar granite. These contain abundant secondary hornblende with the following pleochroism :—

Danta.

$\mathfrak{a}$ = light yellow-green.
$\mathfrak{b}$ = dark green.
$\mathfrak{c}$ = blue-green.

Absorption :— $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$

Correlation with Jodhpur.

The E.–W. strike of the post-Malani basic rocks in the south-western part of the State has already been noticed. The other post-Malani basic rocks in Sirohi do not appear to follow any well-defined direction. In this connection, it is worthy of note that La Touche states :—[1]

Strike.

'The volcanic period was succeeded by the intrusion into the complex of lava and granite of a number of basic dykes, the material of which is an altered olivine dolerite or diabase consisting of plagioclase felspar, olivine and augite with a small amount of biotite. The interval that elapsed before the intrusion of these dykes cannot be ascertained, but it must have been sufficient to allow

[1] *Mem. Geol. Surv. Ind.*, XXXV, p. 25, (1902).

of the development in the lavas and granites of joint planes, since the dykes usually follow such planes. The majority of the dykes run north and south, but another system crosses these almost at right angles. There does not seem to be any difference in composition between the rocks of each system. They appear to have been injected before the deposition of the overlying Vindhyan sandstones, since they have not been found traversing these, but as it happens, none of the dykes were observed, even among the lavas, in that part of the country where the remnants of the sandstones are now visible, and it is quite possible that the dykes are of post-Vindhyan age. Mr. Blanford mentions an outburst of "basalt" in connection with the Talchir boulder beds of Pokaran, but he says that the relations of the rocks are not clear.'[1]

Absence of Vindhyans in Sirohi.

Unfortunately there are no Vindhyan sandstones in Sirohi State from the field relations of which information might have been gained concerning the age of these post-Malani basic rocks. La Touche's conclusions are that the post-Malani basic rocks were pre-Vindhyan, but he admits the possibility of their being post-Vindhyan in age. The author is inclined to correlate the post-Malani basic rocks of Sirohi with those of Jodhpur and agrees with La Touche in believing them to have great antiquity. He does not consider them to have genetic relationship with the Deccan trap lavas, which are thought to be much younger than the post-Malani basic rocks of Sirohi State.

[1] *Rec. Geol. Surv. Ind.*, X, p. 13, (1877).

CHAPTER XII.

POST-TERTIARY AND RECENT DEPOSITS.

Blown Sand.

Blown sand is especially plentiful in those parts of Sirohi State occurring on sheets 75, 76, 93 and 94. The large Nandwara Hill rises in the north-eastern part of sheet 76. Blown sand is heaped near the south-western flanks of this hill, and also the western flanks of the ridge with the peaks 2,280 and 1,945 feet for a very considerable depth, which, in the former case, must be measured in hundreds of feet. High sand hills occur also on the leeward (eastern) side of the hill 1,945 feet. La Touche has mentioned the occurrence at western end of the Saora range of sand over 800 feet thick,[1] but it is doubtful if any of these Sirohi deposits attain that thickness. These sand hills on sheet 76 in the south-western part of the State have been the scene of more than one sanguinary conflict between Jodhpur and Sirohi in the days before peace came to the land.

Sheet 76.

The feature noted by La Touche[2] whereby the sand hills are separated from the rocky knolls by a deep ravine, kept clear by the drainage from the hill sides and eddies of wind, was also found to be the general case in Sirohi. The loosely packed sand offers no resistance to the erosive action of streams during the few months of the year that rain falls; but the persistent wind soon more than makes up the leeway during the ensuing hot weather, and so the wind-blown sand steadily encroaches ever more eastward.[3]

Easily eroded nature.

A 'bay' of wind-blown sand extends from sheet 76 on to sheet 96 in the vicinity of the villages of Jirawal, Bikanwas, Basan, Khan and Warman.

Sheet 96.

Sand is heaped near the south-western part of the Sunda hills on sheet 75, stretching into Jodhpur where it is developed in force.

Sheet 75.

[1] *Mem. Geol. Surv. Ind.*, XXXV, p. 37, (1902).
[2] *Op. cit.*, pp. 38-39.
[3] *Cf* Dr. Heron's remarks in *Mem. Geol. Surv. Ind.*, XLV, p. 103, (1917).

Wind-blown sand is banked up against the rhyolitic and granitic hills in the northern part of the state on sheet 94; no rocks crop out in that part of Sirohi on sheet 93 in the extreme north.

Sheet 94.

Reference to the origin of the wind-blown sand of Jodhpur was made by La Touche[1] and valuable evidence in support of La Touche's contention that it was not all of local origin has been given by Sir Thomas Holland and Dr. W. A. K. Christie.[2] Though there are no salt deposits of economic value in Sirohi State, yet much of the saline character of certain of the wells in the plains must be due to the solution of salt carried by wind from the Rann of Cutch.

Origin of sand.

Talus.

As has been noted by Dr. Heron,[3] talus slopes are prominent features of the quartzite, shale and to a lesser extent mica-schist hills and are not characteristic of granite and limestone hills. The Malani rhyolites and dellenites usually have distinct talus slopes and the same feature is characteristic of the Mundwara suite of igneous rocks. It is very rarely indeed that these slopes are cemented.

Rocks characterised by talus slopes.

Alluvium.

The amount of alluvium (undifferentiated from wind-blown sand and soil) shown on the map is considerably less than that which actually occurs in the State. Most of the stream courses have thin sheets of alluvium on their sides and it is not possible to show these in a map of the scale upon which mapping was carried on (one inch to the mile). By the nature of the deposit, the boundaries of the alluvium with the rocks must always be indefinite, and where there is undoubted evidence that the rock beneath the soil-cap or alluvium is of a certain kind, this rock has been mapped in preference to the less informative alluvium.

Undifferentiated from wind-blown sand and soil.

In the lower parts of their courses, the chief rivers meander through a plain with occasional hills which, to all intents and purposes, may be regarded as almost a peneplain. Accordingly the deposits of alluvium along their

Amount of denudation.

[1] *Op. cit.*, pp. 38-41, (1902).
[2] *Rec. Geol. Surv. Ind.*, XXXVIII, pp. 154-186, (1910).
[3] *Mem. Geol. Surv. Ind.*, XLV, p. 100, (1917).

lower courses are much greater than elsewhere. One must be amazed at the amount of denudation that has taken place since Delhi and Malani times. The blanket of rocks under which the Erinpura and Idar granites crystallised out has been removed and much of the granites themselves denuded. It is only an infinitesimal part of this denuded material that has been deposited within the limits of the State and that only at a very recent period in the form of alluvium. No doubt the denudation of so much material from this old land area has been compensated to a very considerable extent by uplift in accordance with the principle of isostasy. The uplift would once again rejuvenate the streams denuding the area and the work of denudation would be resumed with new intensity. But there is but little evidence of such rejuvenation now visible, except perhaps in the south-eastern part of the State. There waterfalls are abundant in the upper parts of the streams which flow through limestone country. This is partly due to the nature of the calcic rocks, but it is also possible that there has been uplift within comparatively recent times. The country here is very suggestive of an old peneplain the rivers running through which have been rejuvenated by some means.

Dr. Heron.

Similar features have been noted by Dr. Heron in North-East Rajputana[1] who suggests that the old plane of erosion represents the land surface at the time when the Jurassic and Nummulitic beds of Jaisalmer were being laid down. It is thought, however, that the ancient peneplain in Sirohi is much younger than that in North-East Rajputana.

Conglomerates.

Frequent occurrence.

Sub-recent conglomerates are quite frequently met in the stream courses draining the plains in the western and south-western parts of the State, and less frequently in the eastern parts. These consist of boulders of varying sizes, roughly cemented together by calcareous material leached generally from the calcic rocks or Erinpura granite. Their extent is extremely local.

[1] *Mem. Geol. Surv. Ind.*, XLV, pp. 8-9, (1917).

CHAPTER XIII.

ECONOMIC SECTION.

Agriculture.

The scarcity of water necessarily limits the amount of agriculture that the State can support. During years with bad rains, there is a wholesale desertion of the less fortunately situated villages and wells.

Limited in amount.

Water is obtained from wells after the watercourses have dried up, the 'Persian Wheel' being the usual method adopted. Salt and fresh water wells are found on the plains, as *e.g.*, near Jogipura (sheet 94). The author was informed that the slightly saline water is used for the cultivation of wheat, but barley will not grow with it; and that the fresh water gives excellent crops of barley but poor wheat crops.

Rainy season crops are usually planted near the hills, which are used for pasturage, and the fields near the village are utilised for cotton at the same time. The surface of these rainy season fields is barely scratched, and the ground is never properly cleared. These temporary fields are allowed to lie fallow during the cold and hot seasons but it is very rarely that the fields near the village get a rest from the cycle of crops they are forced to bear.

Wells are usually owned by three or four cultivators whose fields are irrigated in turn. Even in the sandiest country, as *e.g.*, in the south-west (sheet 76) and north (sheet 94) of the State, careful irrigation gives remarkably good crops. The cultivated fields usually surround the villages. However, the *Girasias* living in the south-eastern part of the State (sheet 97) do not form centralised villages; their usual practice is to build their houses in the vicinity of their fields, giving straggling villages, sometimes miles in length, usually along the banks of a stream.

Few vegetables are grown except in the neighbourhood of large towns and near Abu Road. The sandy beds of the larger streams, not quite dried up, are often used for the cultivation of vegetables, the small flow of water being diverted into the furrows (between the rows of vegetables) which have been easily and quickly made.

Ballast, Railway (*see* Building Stones).

Building Stones (also *see* Limestone).

Abundant building stones.

The State is rich in stone which can be utilised for building purposes, but there are no deposits of first quality, well-jointed, easily worked and favourably situated material for the development of an export trade. There is, however, ample material to supply all local needs and a sufficiency of limestone from which lime may be obtained.

Limestone slabs.

The purity of the available limestone has been discussed under another section (*see* pp. 156-159). The following particulars concerning the white marble or crystalline limestone from Perwa and Serwa (sheet 96) were obtained in March, 1927. The costs of smoothly finished slabs of limestone were as under :—

2′ 8″ × 1′ 6″ × 0′ 4″ =	Rs. 8-0-0	per slab.
1′ 0″ × 1′ 2″ × 1′ 0″ =	„ 2-4-0	„
2′ 7″ × 2′ 7″ × 0′ 6″ =	„ 10-0-0	„
2′ 4″ × 3′ 8″ × 0′ 6″ =	„ 15-0-0	„
2′ 0″ × 2′ 0″ × 0′ 2″ =	„ 4-0-0	„
1′ 1″ × 7′ 0″ × 1′ 0″ =	„ 15-0-0	„
1′ 6″ × 8′ 0″ × 1′ 6″ =	„ 40-0-0	„

It will be noted that the cost per slab rises very disproportionately to the length of the slab; a very small increase in length demands a very enhanced price. The rates of pay of the workmen are those quoted for lime workers in the same quarries (*see* p. 159). There are no prominent joint planes in the stone. Such dip as could be seen at Serwa appeared to be vertical; at Perwa no main direction could be seen. Reference may be made to the limestone section for a few brief notes concerning occurrences of other limestone and marbles used as building stones.

Railway ballast.

The grey Delhi limestones so abundant north of Abu Road have been extensively utilised by the Bombay, Baroda and Central India Railway as ballast. The stone quarried near Murthala[1] is, it is believed, practically the only ballast used on the railway from Ahmedabad to Marwar Junction. The extraction of the stone has been facilitated by the construction of a small branch railway.

[1] *Rec. Geol. Surv. Ind.*, LIX, p. 49, (1927).

Erinpura granite.

The Erinpura granite is frequently used as a local building stone, but it is not well jointed and so is not easy to work. The foliated types split rather more easily than the granitic types and full advantage is taken of this by the local workmen. Both the foliated and unfoliated kinds give handsome stones which are easily rough-dressed. All sizes of grain are available from coarse easily weathered stones to fine-grained highly resistant material.

Malani rocks.

The Idar granite, with its dominant pink colour due to orthoclase felspar, is, as a rule, entirely different in appearance from the Erinpura granite. Except in certain porphyritic varieties, it is generally well jointed but it has been used locally only to a limited extent. Some of the felspar porphyries and granite-porphyries would make excellent and handsome building stones; they are well jointed and easily worked. Their occurrence, however, is far removed from any railway station. The Malani rhyolites would form an unusual and distinctive stone but the colours vary greatly within short distances.

Basic rocks.

The gabbros from Chandrawati and Kui near Abu Road (sheet 97) would form a very handsome dark-coloured stone when polished. However they weather spheroidally, and as they possess no well-marked system of joints, they would be difficult to work. The same remarks are applicable to the great majority of the numerous doleritic and epidioritic rocks in the State.

Alkaline syenites.

The sodalite-syenites from near Mundwara (sheet 95) would form a handsome, light-coloured rock when polished. There are certain joints which would assist their extraction. The amount of the syenites is strictly limited and they are, as a rule, very variable in texture within a short distance, though the usual variety is coarse-grained. Moreover they are situated on the plains west of the Abu-Erinpura range and so are far removed from the nearest railway station (Rohera or Pindwara).

Aravallis.

The fissile Aravalli schists and phyllites find a small local use as a material for building huts.

Delhis.

The Ajabgarh quartzites (Delhi) in the south-eastern part of the State could be used as a building material as certain exposures are well jointed. The stone cannot be compared, however, with the Upper Bhander sand-

stone of Vindhyan age which has been utilised over large parts of Rajputana.

Roads.

By far the greater proportion of the local roads are unmetalled, but in the vicinity of the capital, Erinpura granite has been used as the chief constituent of certain motor roads. As a rule these have been surfaced with a very felspathic gravel formed by the weathering and decomposition of the granite. This gravel gives a good surface which stands up well to the small amount of traffic to which it is subjected. The same material has been used on the P.W.D. road from Abu Road to Abu, which is a fine piece of engineering construction work. During the author's last visit, however, in April, 1931, tar-spraying was being employed. The frequent inclusions of basic rocks in the granite have also been utilised on this road.

Clays.

No large deposits of economic importance.

As in all parts of India, local potters utilise the clays which are developed in the village 'tanks', especially when those 'tanks' are situated on argillaceous Aravallis or Delhis. These amply serve their needs. Local deposits of kaolin of varying size are quite common in the plains to the west of the Abu-Erinpura ridge. They are formed through the breaking down of the felspars of the Erinpura granite, but the decomposition of the felspars is, as a rule, very sporadic and no deposits of sufficient purity or extent to have economic importance were noted throughout the course of the survey.

Copper (also *see* Gold).

Doubtful presence.

The doubtful presence of chalcopyrite was recognized in a specimen said to have been collected from a pit dug for the extraction of gold, 1½ miles N. N. W. of Rohera (sheet 119).

Garnets (*see* Gem Stones).

Gem Stones.

Garnets.

Garnets are not so commonly found in the Aravallis and Delhis as might be expected, it being quite exceptionally that the schists of these systems are garnetiferous. In the south-western corner of the State, however,

where composite-gneiss has been formed from the Aravalli rocks by the profuse *lit-par-lit* injection of the pegmatite accompanying the Erinpura granite, garnets are rather common. They also occur in the vicinity of Balda (sheet 95). These garnets may be picked up in stream courses but their size is small and they are never clear, being opaque and fractured; they thus have no value as gem stones.

Tourmaline.

Tourmaline is a common constituent of the pegmatite accompanying the Erinpura granite but the variety found is always the black schorl; the red (rubellite), blue (indicolite), green or brown varieties, which have economic value, were not seen.

Topaz.

Topaz is doubtfully recorded in a tourmaline-bearing aplitic rock from $1\frac{1}{4}$ miles north of Amlari (sheet 95). This is the sole occurrence and it has merely mineralogical interest.

Gold.

Hughes and La Touche.

Reference has already been made to La Touche's visit to the village of Rohera (sheet 119) in connection with a reported find of gold and copper by Major F. C. Hughes of the Erinpura Irregular Force.[1] A brief reference to the author's inspection was made in the General Report of the Geological Survey of India for 1925.[2]

Examination of old pits.

The author examined two old pits about $1\frac{1}{2}$ miles N. N. W. of Rohera from which it was stated gold had been extracted. The ore was supposed to have been carted to Rohera and crushed there. It was further stated that only one cart-load was taken and then further removal was prohibited by the Durbar; but the author is unable to vouch for the truth of this statement. It was affirmed that As. 12 were all that resulted for every rupee spent in the venture.

The pits had long since fallen into disrepair and when excavated specimens were examined, no trace of gold could be seen nor even a trace of pyrites. The author was given a specimen (34/233,

[1] *See* p. 7. Also T. H. D. La Touche, *Gen. Rept. Geol. Surv., Ind.*, 1898-99, p. 45, (1899).

[2] *Rec. Geol. Surv. Ind.*, LIX, p. 44, (1927).

16194) said to have been taken from a pit some 20 to 30 years previously. This shows abundant cubes and octahedra of pyrite, the identification of which was confirmed by the blowpipe; the thin section shows pyrite, ? chalcopyrite, quartz, tremolite, chlorite, epidote and plagioclase felspar. A part was crushed and assayed for gold, but with negative results.

Iron-ore.

None of the iron-ore occurrences in the States have economic value. Magnetite is an extraordinarily constant constituent of most of the igneous rocks and this occasionally has been concentrated in the sands of the stream courses which drain hills composed of basic igneous rocks. Thus in the vicinity of Mundwara (sheet 95), the black iron-ore constitutes the major part of the sands of the stream beds.

Magnetite.

Iron-ore in the form of magnetite, ilmenite, haematite and limonite also occurs but disseminated through the rocks and so with no economic value. Iron-ore was noted occasionally in the pegmatite accompanying Erinpura granite but never in any useful amount. It is rare indeed in Rajputana that a state of the size of Sirohi is so badly provided with supplies of iron-ore. There is consequently no old native iron industry, though occasionally slag heaps were noted where past native workers had utilised certain ferruginous Aravalli or Delhi rocks.

Other oxides.

Kankar (*see* Lime).

Kaolin (*see* Clays).

Lime, Limestone and Marble.

The field relationships of the various limestone and marble occurrences have already been given in the descriptions of the Aravalli and Delhi rocks. As limestone is by far the most important rock from an economic standpoint which is found in the State, the following analyses,

Analyses.

carried out chiefly by Mahadeo Ram in the laboratory of the Geological Survey of India, may prove of value:—

TABLE IX.

	I	II	III	IV	V	VI	VII
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble residue	6·70	12·24	3·92	3·96	16·16	8·52	10·64
Fe_2O_3, Al_2O_3	1·07	2·87	1·17	0·67	0·74	0·54	4·06
CaO	49·63	42·50	52·12	49·55	47·89	51·49	47·94
MgO	1·66	2·96	1·08	3·47	0·70	0·91	2·79
Loss on ignition	40·54	38·26	42·53	42·34	34·82	39·36	35·33
TOTALS	99·60	98·83	99·92	99·99	100·31	100·82	100·76
Specific gravities	2·76	2·71	2·72	2·74	2·86	2·72	..

I. Grey Delhi limestone (36/158), half a mile south-west of Dhanwau (sheet 96) and two miles north of Abu Road (sheet 97) (Mahadeo Ram).
II. Grey Delhi limestone (34/232), four miles south-west of Garh (sheet 119) (Mahadeo Ram)
III. Grey Delhi limestone (34/258), just south of Watera (sheet 96) (Mahadeo Ram).
IV. White Aravalli marble (36/770), Piloti (sheet 76) (Mahadeo Ram).
V. White Delhi marble (36/769), Ghoratankri (sheet 97) (Mahadeo Ram).
VI. White Aravalli marble (36/768), Perwa (sheet 96) (Mahadeo Ram).
VII. Delhi phlogopitic limestone (34/251), 1½ miles north of Nawawas (sheet 119) (L. R. Sharma).

Abu Road.

A certain amount of burning for lime is carried on with the grey Delhi limestone which occurs in abundance to the north of Abu Road, but the chief importance of this stone lies in its utilisation as ballast by the Bombay, Baroda and Central India Railway (*see* p. 152). The author was informed, however, that the lime obtained from this stone was sent as far away as Ahmedabad, Palanpur and Ajmer. The first analysis in Table IX shows the large insoluble residue amounting to 6·70 per cent., with iron-oxide and alumina amounting to 1·07 per cent., which this grey Delhi limestone contains. This is probably a good indication of the impurity of the rock,[1] thin sections of which show the presence of quartz and phlogopitic mica.

Garh.

The Garh limestone, likewise of Delhi age (Analysis II in Table IX), also contains a large percentage (12·24) of insoluble residue. This limestone is typical of the large spread of these rocks found in the hills in the north-eastern part of the State. A certain amount of burning for

[1] *See* also *Rec. Geol. Surv. Ind.*, LIX, p. 49, (1927).

lime is carried on but the economic importance of these rocks from that standpoint must be considered small in view of their impurity.

Watera.

Another of the grey Delhi limestones from just south of Watera (Analysis III in Table IX) shows considerably less insoluble matter than the preceding specimens.

Nawawas.

The phlogopitic limestone of Delhi age from north of Nawawas contains the large percentage of 10·64 of insoluble matter.

Jhariwao (?).

According to the Rajputana Gazetteer,[1] the white marble of which the beautiful Jain temples at Dilwara on the top of Mount Abu are built, comes from near Jhariwao on the south-eastern frontier of the state. This village is not shown on the map and it is possible that the marble employed at Dilwara came from the neighbouring state of Danta.

Ghoratankri.

The occurrence of marble near Ghoratankri in this region, however, has already been noted (*see* p. 42) and an analysis of a specimen from there has been given in Table IX above.[2] The marble occurs mainly on the western side of the isolated limestone hill at Ghoratankri; the eastern, northern and southern sides show many dolerites which stretch eastwards across the river to the exposures of calcic rocks on its other side. The southern portion of these calcic rocks across the river is a rather pure marble, but it is just on the border with Danta State.

The former deposit, that nearer Ghoratankri, has a good colour but it is very variable in texture. Generally it is fine-grained and is perhaps best described as a crystalline limestone merging into a marble. There is a fair amount of coarser-grained, but softer, rock in the southern part of the hill.

The deposit on the border, across the river, is a fine white saccharoidal marble, but its amount is limited on account of the profusion of intrusive doleritic and epidioritic dykes, and of veins of pegmatite and granite from the Gorsa outcrop of Erinpura granite.

This Ghoratankri rock takes a good polish. Its analysis shows a high percentage of insoluble matter and though purer material undoubtedly exists, the limitation of supplies lessens its economic value. Moreover it is about 12 miles from the nearest railway station (Abu Road) and means of communication are poor.

[1] III-A, p. 265, (1909).

[2] *See* also *Rec. Geol. Surv. Ind.*, LXI, p. 27, (1929).

Piloti.

The Piloti (sheet 76) Aravalli marble occurs in two outcrops separated by mica-schists.[1] The first outcrop is a small ridge, 120 yards long and 20 yards wide. The second is a hill about 60 to 80 feet high. The latter has been, and is being, burnt for lime and the former quarried, though its value as a building stone is reduced on account of the absence of any well-defined system of joints. The analysis given previously (Analysis IV in Table IX on p. 157) indicates a fairly pure marble with some dolomite. There are numerous small outcrops of calcic rocks in this vicinity, *e.g.*, at Maraichi (sheet 96), Godwara, Bhilra C (sheet 76), etc., some of which are sufficiently pure and metamorphosed to warrant their being termed marbles or crystalline limestones. As noted before, however, impure calcic rocks occur associated with these (*see* p. 29).

Perwa and Serwa.

The Perwa and Serwa (sheet 96) occurrences of crystalline limestones and marbles have been noted elsewhere.[2] These are used to some extent as building stones (*see* pp. 29, 152) and also for the extraction of lime. The analysis given above (Analysis VI in Table IX) shows a large percentage (8·52) of insoluble residue but little iron or magnesia. In 1927, the cost of wood for use in burning the limestone at Serwa for lime was Rs. 3 per bullock cart load. The cost of 14 maunds of lime, delivered in Sirohi, some 27 miles to the north-east, was Rs. 10-12, As. 12 going to the State. The rates of pay per diem from 8 A.M. to 7 P.M. were As. 8 for a man, As. 3 for a boy, and As. 2 for a woman.

Kankar.

Abundant *kankar* was noted throughout the State, more especially in the arid regions in the west adjoining Jodhpur State. With the abundant supply of almost pure lime thus easily available, it is not to be wondered at that this source is frequently preferred to the less pure, though more abundant, calcic rocks.

Mica.

Sabela.

Reference has been made elsewhere[3] to the occurrence of a pegmatite, two miles east of Sabela (sheet 118), which contains muscovite of fair size but too small and of too poor quality to be worked. Both mus-

[1] *Rec. Geol. Surv. Ind.*, LXI, p. 28, (1929).
[2] *Ibid.*, p. 27, (1929).
[3] *Op. cit.*, LIX, p. 49, (1927).

covite and biotite, the latter less frequently, were often noted in the pegmatite accompanying the Erinpura granite; but though diligent search was made, no single instance can be recorded of mica of sufficient purity and size to have any value economically.

Quartz, Rock Crystal.

Reef-quartz.

There are numerous white hills of reef-quartz, which is a pegmatitic derivative of the Erinpura granite, that could be quarried for an abundant and cheap supply of relatively pure silica. No rock crystal was noted in the state. A few specimens were occasionally seen of rose-coloured quartz which, however, were too variable in colour to have any value.

Road Metal (*see* Building Stones).

Soils.

Granites.

The soil resulting from the disintegration and decomposition of the various granites and other rocks found in the State suffice to support a varied flora and a limited agriculture. The Erinpura granite, by reason of its coarseness of grain, gives rise to a gritty soil in which white fragments of felspar and quartz predominate. This coarse soil is characteristic of the plains to the west of Abu. The younger Idar granites at Ban, Isri and Nandwar Hill give a somewhat similar soil, reddish in colour, containing abundant orthoclase felspar. This soil is finer-grained than that formed by the distintegration and decomposition of the Erinpura granite. It supports a more varied flora than the latter at similar altitudes.

Aravallis and Delhis.

The Aravalli and Delhi rocks give a very poor soil as a rule. The calcic rocks of both systems and the intrusive basic rocks of varying ages, however, give better soils. This is only to be expected when it is remembered that of all the ordinary essential mineral constituents of sedimentary rocks, free quartz, which is usually the most abundant, is the most refractory towards purely chemical agencies. This mineral suffers only from mechanical disruption and the silica which is removed during the process of decomposition of rocks comes mainly, from the silicates and not from free quartz.[1]

[1] G. P. Merrill, 'Rocks, Rock-Weathering and Soils', London, p. 234, (1897).

Topaz (*see* Gem Stones).

Tourmaline (*see* Gem Stones).

Water Supply.

Reference has been made previously to the scanty rainfall of the State. The consequence of this is that wells are almost universally used as a supply of water after the end of January, most of the smaller streams having dried up by that time. The larger streams still show a slight flow of water which in places persists even to the beginning of the next rains.

Scanty rainfall.

The actual amount of run-off throughout the State is very small on account of the sandy nature of the soil, which allows downward percolation of the greater part of the rainwater. The level of the water-table is fairly high, but the intense desiccation to which the land is subject during the months of March to June soon has its effect in lowering the level of the water-table. Also the amount of water removed by means of wells is very large and it is only a small proportion of this which finds its way down once more to be utilised in irrigation.

Water-table.

Numerous earthen *bunds* are in general use to conserve the limited supply of rainwater, but only very few 'tanks' in the State are of sufficient dimensions to withstand continual use and evaporation throughout the winter and summer months. Consequently the wells are compelled to supply water for the live-stock upon which the villagers depend so much. It is only very occasionally that masonry or cement-concrete dams are constructed.

Dams.

From his visits to every part of the State, the author concluded that insufficient attention was given to the very important question of the conservation of water. It is admitted that ideal sites for the construction of large reservoirs are few and far between. The question of expense and recompense also has to be considered, and the author was often told that there is but little need for large reservoirs, which are costly and would not supply more water than is obtained from primitive methods at the present time. The excessive amount of evaporation that would take place from the surfaces of large reservoirs also must not be forgotten. So there is much to be said for allowing the present primitive, and admittedly inefficient, methods to continue.

The constant presence of water at a small depth below the surface is frequently indicated by a collection of *khajur* or wild date palms. Most wells are sunk not far distant from river courses, which are rivers for but a few months in the year. The water-table under these is as a rule high but descends the further one goes from their banks. There is a slow but definite underground flow of water from the higher parts of these stream courses towards the far distant sea and this assists in keeping the water relatively fresh. But on the plains, more especially in the western and north-western parts of the State, the evaporation and solution which goes on is sufficient to make the water of most wells definitely saline.

Wells.

Sinking wells into the solid undecomposed rocks such as Idar or Erinpura granite almost invariably leads to failure, except in the lucky cases in which water-containing fissures are met. This elementary fact is known to the villagers, who sink their wells in rocky country in the thin layer of soil and gravel on the sides of the streams flowing through the area. This method is not without its disadvantages in populous districts. Thus the water supply of the hill station of Abu is generally obtained from wells which are sunk in the thin overburden of soil and gravel along the streams. Most of the drainage of the hill station finds its way into these stream courses, with the result that epidemics due to bad water supply are not at all infrequent in that otherwise salubrious hill station.

It is interesting to record that just below the summit of Guru Sikkar, the highest point of Mount Abu, two wells have been constructed for the use of pilgrims, and these give a good supply of water. They have fortunately been sunk so as to tap a water-bearing fissure.

CHAPTER XIV.

STRUCTURE OF SIROHI STATE.

Conclusions from Exposures in Sirohi.

Intrusion of Erinpura granite.

The following brief *résumé* gives such conclusions as can be drawn from exposures in the State itself.

It has been emphasised in more places than one that the dominating forces which have left their imprint on the rocks in Sirohi immediately preceded the intrusion of the Erinpura granite. Before this, however, the Aravallis were folded and eroded, and the upper members of the Delhi system, *viz.*, the Ajabgarh series, deposited upon their eroded edges. The mass of Erinpura granite forming the Abu *massif*, has been depicted diagrammatically in Figures 4 and 5 as having been intruded more or less at, or under, the westermost extension of the Delhis.

Structure of Aravallis.

The present structure of the Aravallis to the west of the Abu *massif* is rather indefinite, but in Chapter III, reference has been made to anticlinal structures near Sindret (sheet 95) and Selwara (sheet 96), and to the rolling dips of the limestones in the south-western corner of sheet 96.

Structure of Delhis.

The Ajabgarhs were folded into broad open folds in the south-eastern part of the State and into steeply dipping strata in the north-eastern corner. The first four sections which form Plate 11 show very well the changing conditions as one proceeds from the south-eastern to the north-eastern part of Sirohi. They are all roughly parallel and their general direction (bearing) varies from 121° to 113°; they are all approximately at right angles to the strike of rocks.

Chandrawati-Jamburi section (sheet 97).

The first section (Plate 11, fig. 1) runs from half a mile N. 67° W. of Chandrawati to three-quarters of a mile south of Jamburi, a distance of 9·35 miles in a direction of bearing 113°. It is the most southerly of the four sections and has especial interest in cutting the intrusive Gorsa mass of Erinpura granite and the fault some 2½ miles north-east of Sur Paga. The fault has been shown as a reversed fault, as the local dips show very considerable distortion due to the near-by intrusion of the Gorsa mass of granite. It is not possible to estimate accurately the throw of the fault

which brings the oldest members of the Ajabgarhs, the quartzites,[1] into juxtaposition with the youngest members. Its throw must be greater than the thickness of the intermediate schists, which is considerable. It would appear to be a hinged fault, with the greatest throw just east of the hill station 2,842 feet.

It is possible that the boundary between the Erinpura granite and the mica-schists near Chandrawati is faulted and that slipping has also taken place at the junction between the schists and calcic rocks in this vicinity. This is evidenced by the presence of brecciated quartzites (*see* p. 35) along this junction due to the brecciation of reef-quartz pegmatites. It will be noted that the section depicts the Chandrawati gabbro as the youngest rock in the area.

Manpur-Bhamoria section (sheet 97).

The second section (Plate 11, fig. 2) has the same length and is parallel to the above; it runs from the Manpur *dâk* bungalow to one mile north-east of Bhamoria. It will be noted in this section that the dips have flattened out very considerably in the passage of some five miles along the strike. The outcrops of limestone in the western part of the section, as in the preceding case, have been depicted as synclinal masses 'pinched into' the older mica-schists. The oldest rocks, quartzites, appear in the centre of an asymmetrical anticline with steeper dips on the western flank. Schists and calcic rocks to the east have been shown as having flat dips, but it must be remembered that their dips change locally to a large extent. The general structure, however, is that of a flat syncline, followed by an equally flat anticline. This structure persists to the intrusive mass of Erinpura granite forming the Bhamoria outcrop, which is just outside the limits of the section.

Kodarla-Waloria section (sheet 119).

The third section (Plate 11, fig. 3) has been drawn some 16 to 18 miles further to the north-east along the strike, which here has changed to approximately N. 30° E.-S. 30° W. The bearing of the section is 121°, which is almost exactly at right angles to the strike. The section runs from Kodarla in the north-west to hill station 2,809 feet in the south-east, which forms a boundary peak between Sirohi and Udaipur. The outcrops of calcic rocks are still depicted as synclinal masses pinched into the older mica-schists, whilst the oldest rocks, quartzites, are highly compressed

[1] *See* p. 42. The doubtful possibility of these quartzites belonging to the Alwar series is admitted.

anticlinal remnants. The massive Waloria outcrop of Erinpura granite is shown on the right of the section.

Jhonkar-Bagdari section (sheet 118).

The fourth section on Plate 11 (fig. 4) represents the structure of the country some eight miles still further along the strike towards the north-eastern corner of the State. It runs at right angles to the strike and bears 117° from one mile north-west of Jhonkar to 1¼ miles south-east of Bagdari. The boundary between the Erinpura granite and the Ajabgarh calcic rocks near Jhonkar is probably faulted. The quartzites are shown as a highly compressed anticlinal remnant.

Sanwara-Watera and Anadra-Deldar sections (sheet 96).

Reference may also be made at this juncture to the two last sections on Plate 11 which show the general relationship of the Aravallis and Delhis with the Erinpura granite and the younger Idar granite or its representatives. The sections are approximately parallel to those described above. Figure 5 runs from the Sanwara *dâk* bungalow with bearing 120° for 19 miles to 1¾ miles S. 60° E. of the village of Watera. Figure 6 runs from 1¼ miles W. N. W. of Anadra with bearing 121° to two miles in the same direction from Deldar. Both sections lie on sheet 96 and may be considered as supplementing the series figures 1 to 4 on the same plate; following along the strike, the order of sections is figure 1 (sheet 97); figure 2 (sheet 97); figure 6 (sheet 96); figure 5 (sheet 96); figure 3 (sheet 119); and finally figure 4 (sheet 118).

Figure 5 on Plate 11 shows the Idar granite near Adli at the junction of the Aravallis and the Erinpura granite. As has been noted previously, this Idar granite was probably intruded along the faulted junction between these rocks. A thin felspar-porphyry has been shown at Undwaria. Synclinal masses of limestone have been shown just past Watera.

Figure 6 (Plate 11) cuts through the hill station of Abu. Limestone is met at and east of Kivarli. Quartzites come in to the south-east of Deldar.

Correlation with other Areas.

Dr. A. M. Heron's work.

Full details concerning the nomenclature and correlation of the Aravalli and Delhi systems are given by Dr. A. M. Heron in his memoir on the Geology of North-Eastern Rajputana.[1] He later came to the conclusion that the un-

[1] *Mem. Geol. Surv. Ind.*, XLV, pp. 105-116, (1917).

conformity between the Alwar series and the Raialo series was so important that the Raialos were removed from the Delhi system and given a place intermediate between the Delhis and Aravallis.[1] A summary of the representatives of the Delhi system in Udaipur and its adjoining States has been given in the General Report for 1930,[2] and Dr. Heron's detailed work will shortly be published.

Chief features of geology of Sirohi compared with other areas.

The chief features of the geology of Sirohi, when correlated with that of its neighbouring States, are (1) the occurrence of contemporaneous volcanic rocks in the lowest members of the Aravallis; (2) the total absence of representatives of the Raialo system; (3) the probable absence of equivalents of the Alwar series and the definite absence of the more local Kushalgarh limestone; (4) the abundant intrusion of basic rocks into the Delhis of the east before the intrusion of the Erinpura granite; (5) the equally numerous intrusions of doleritic rocks into the Erinpura granite and Aravallis of the west; (6) the occurrence of gabbros at Chandrawati and Kui and of picrites, gabbros, pyroxenites, dolerites and sodalite-syenites, etc., at Mundwara; (7) the very strong development of the Idar granite and its hypabyssal and volcanic representatives; and finally (8) the well-developed system of post-Malani basic rocks in the south-western part of the State.

[1] *Rec. Geol. Surv. Ind.*, LXII, pp. 172-173, (1930).
[2] *Op. cit.*, LXV, pp. 133-137, (1931).

INDEX.

The longitudes given in this Index are those of the new degree (quarter-inch) sheets. The corresponding values for the old one-inch sheets of the Central India and Rajputana Survey, the numbers of which are given in parenthesis immediately preceding the latitudes, may be obtained by adding 2′ 30″ to the given longitudes.

N

Q

MGIPC—M—VIII-4-9—12-7-33—650.

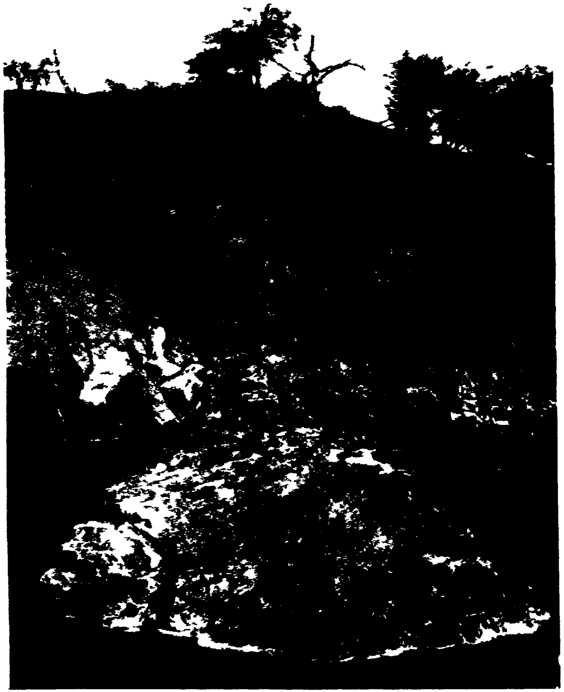

FIG. 1. MALANI FELSPAR-PORPHYRY DYKE INTRUDING ARAVALLI PHYLLITIC ROCKS IN A RIVER SECTION AT TOKRA

A M Heron Photo

FIG 2 RAMIFYING BASALTIC DYKES INTRUDING ERINPURA GRANITE, 1 1/4 MILES WEST (A LITTLE SOUTH) OF KARJARA KHERA.

A L Coulson Photo

G S I Calcutta

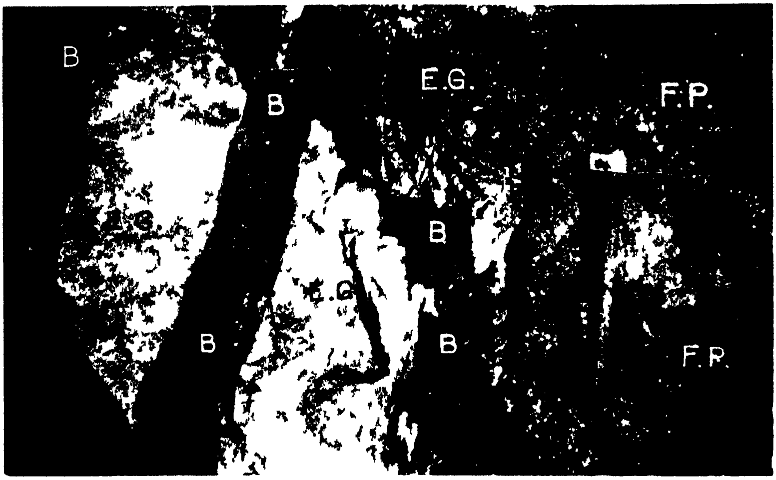

FIG 1 APLITIC ERINPURA GRANITE (E G) INTRUDED BY BASALTIC DYKES (B) AND THE WHOLE INTRUDED BY A FELSPAR PORPHYRY (F P) OF MALANI AGE, 1 MILE N N E OF BILANGRI

FIG. 2 INCLUDED FRAGMENTS OF A POST-ERINPURA-GRANITE DOLERITIC DYKE IN PORPHYRITIC IDAR GRANITE, 1 3/4 MILES S S W OF PARDI

A L Coulson photos. *G S. I Calcutta*

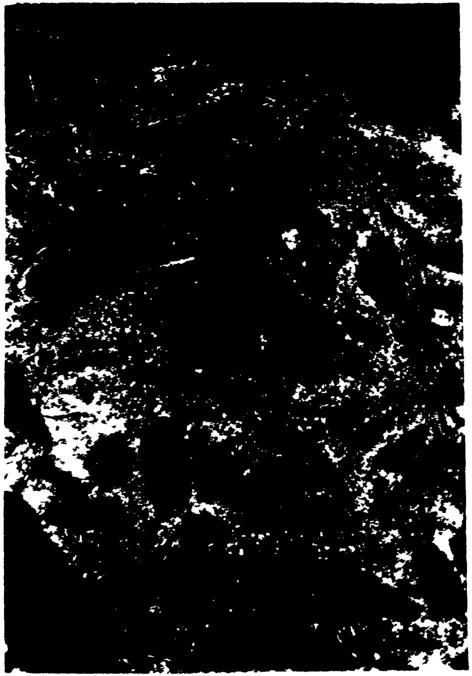

FIG 1 INCLUDED FRAGMENTS OF A POST-ERINPURA-GRANITE DOLERITE IN A MALANI FELSPAR-PORPHYRY, HALF A MILE SOUTH-WEST OF DANTA .

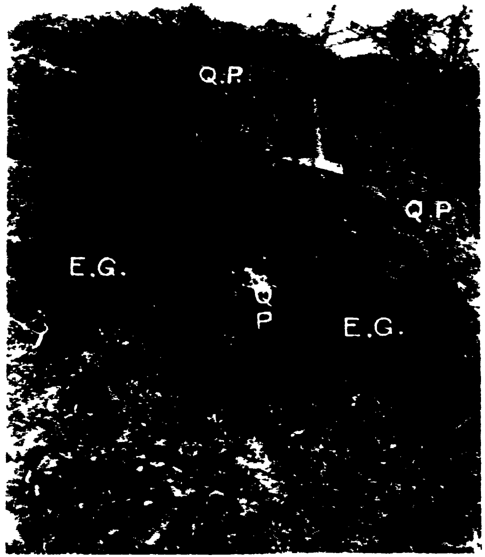

FIG. 2 JUNCTION OF A MALANI QUARTZ-PORPHYRY (Q. P.) WITH ERINPURA GRANITE (E. G) WHICH IT INTRUDES TWO MILES S S. W. OF SILOI.

A. I. Coulson photos.

G. S. I., Calcutta.

FIG 1 GRANITE PORPHYRY DYKE SOUTH EASTERN END OF THE VILLAGE OF SANWARA

FIG 2 FELSPAR-PORPHYRY DYKE, HALF A MILE NORTH OF TOKRA, LOOKING NORTH-WEST

A M. Heron photos. *G. S. I , Calcutta*

FIG 1 VIEW FROM THE WESTERN SLOPES OF HILL STATION 3 220 FEET, NANDWAR HILL, looking across the plains to Boreta Hill in Jodhpur The hills are formed of Idar granite

FIG. 2. VIEW OF THE SUNDA HILLS, LOOKING TOWARDS MALASER MAHADEO. The hills are formed of Idar granite.

A. J. Coulson, Photos

G. S. I., Calcutta

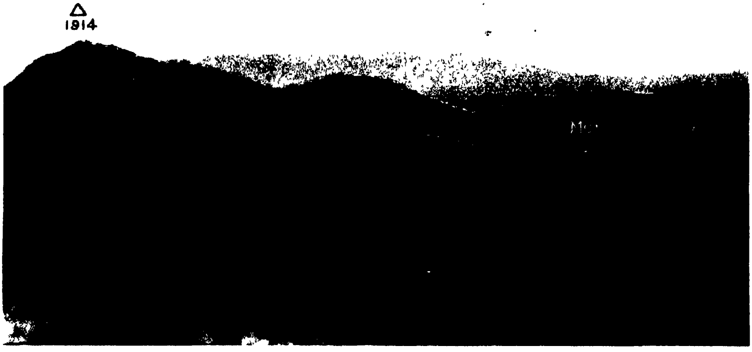

FIG. 1. THE MER RING OF HILLS LOOKING W. N. W. FROM HILL STATION 1,670 FEET, NEAR MUNDWARA. The slopes of hill station 1,914 feet are formed of basaltic rocks. The dark rock in the immediate foreground is dolerite forming part of hill station 1,670 feet. The dark rock forming the far side of the ring is also dolerite. The light-coloured rock forming the low hills in the centre foreground is Erinpura granite. The Sunda hills of Idar granite in Jodhpur may be seen in the background.

A. L. Coulson, photo. *G. S. I., Calcutta.*

FIG. 2. HILL STATION 2,181 FEET AND SURROUNDING HILLS, COMPOSED OF IDAR GRANITE. Erinpura granite forms the Abu *massif* seen dimly in the right background. The photograph was taken from south-east of Mirpur.

A. M. Heron, photo. *G. S. I., Calcutta.*

FIG. 1. HILL STATION 2,181 FEET AND THE ISOLATED HILL 1 1/2 MILES E. S. E. OF MOSAL, both of which are formed of Idar granite. Sand forms the northern slopes of the former hill.

FIG. 2. RIDGE OF PORPHYRITIC IDAR GRANITE, 1 3/4 MILES N. N. W. OF HARNI. The low-lying country in the foreground is composed of Erinpura granite. The high ridge in the left background forms part of the Sunda hills in Jodhpur which are composed of Idar granite.

A. L. Coulson, photos *G. S. I. Calcutta.*

FIG 1 INCLUDED FRAGMENTS OF A BASIC ROCK IN ERINPURA GRANITE, TWO MILES EAST OF PHACHARIA

FIG 2 SHOWING THE WEATHERING OF IDAR GRANITE, TWO MILES E S E OF MOSAL

A. L Coulson photos

G S I Calcutta

FIG 1 A 'RIGHT' BAVENO TWIN, of composition 70 per cent An, and other twinned felspars in an Aravalli basalt (17042, × 37, crossed nicols).

FIG 2 A 'FOURLING' BAVENO TWIN, the individuals of which are also twinned according to the Carlsbad law, in an olivine-basalt intruding Erinpura granite (17047, × 54, ordinary light).

FIG. 3. SPHENE CRYSTAL, WITH CENTRE OF ILMENITE, in Erinpura granite (16241; × 120, ordinary light).

FIG. 4. RIMS OF HORNBLENDE CRYSTALS around quartz phenocrysts in a porphyry (17066; × 46, ordinary light).

A. L. Coulson & L. R. Sharma, photomicros.

G S. I. Calcutta.

FIG 1. MICROGRAPHIC INTERGROWTH OF QUARTZ AND FELSPAR IN PORPHYRITIC IDAR GRANITE (21163, ×51, ordinary light).

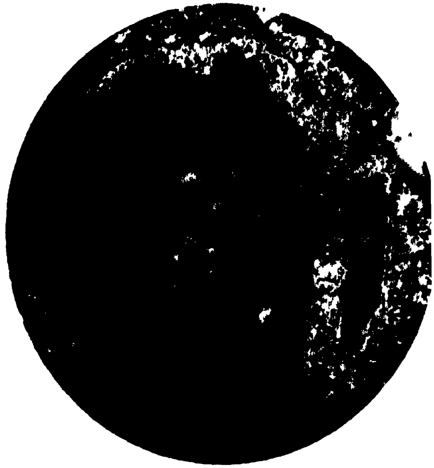

FIG 2 LARGE ORTHOCLASE CRYSTAL IN QUARTZ-FELSPAR-PORPHYRY (17060) SHOWING MARGINAL DEVELOPMENT OF MYRMEKITE (× 60, ordinary light)

FIG. 3. LATHS OF PREHNITE IN CONTACT METAMORPHIC ROCK (17601 A; × 79, ordinary light).

FIG. 4. ZONED DIOPSIDE IN AN AMPHIBOLITE (17037; × 54, ordinary light).

A. L. Coulson & L. K. Sharma, photomicros.

G. S. I. Calcutta.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA

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VOLUME LXIII, PART 2.

THE IRON-ORE DEPOSITS OF BIHAR AND ORISSA. BY H. CECIL JONES, A.R.S.M., A.R.C.S., F.G.S., *Superintendent, Geological Survey of India.* (With Plates 13 to 32.)

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PART I—GEOLOGY.

CHAPTER I.

INTRODUCTION.

General.

The iron-ore area described in this memoir is situated some 150 to 200 miles to the west of Calcutta in the Province of Bihar and Orissa. It includes the southern part of the Singhbhum district, in the south-west part of which is the Government estate known as the Kolhan, and parts of the Feudatory States of Bonai and Keonjhar.

The area under description lies between latitude 21° 45′ and 22° 30′ and longitude 85° 00′ and 86° 00′. In my preliminary account of this area[1], I stated that 'Good iron-ore is reported to occur in the Feudatory State of Pal Lahara'. I have since had an opportunity of examining the Malayagiri Hill in which this iron-ore was supposed to occur. Good hematite occurs in a hematite-quartzite, but the quartz and hematite are so intimately mixed

[1] H. C. Jones, 'The Iron Ores of Singhbhum and Orissa', *Rec. Geol. Surv. Ind*, LIV, p. 203, (1923).

together that only a very hard, low-grade siliceous ore can be obtained, which is of no economic value at the present time.

The following sketch map gives the location of the iron-ore areas

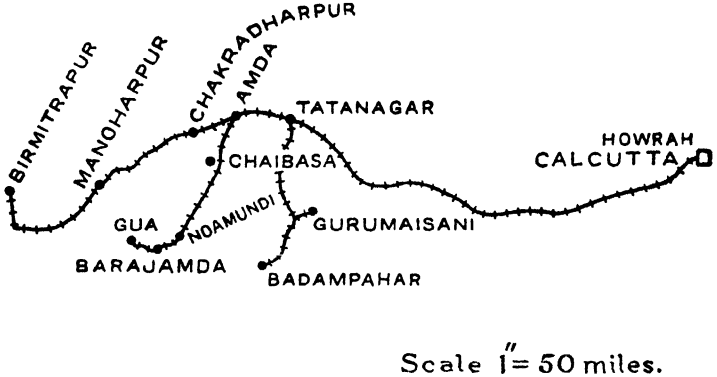

FIG. 1.—Sketch map showing position of iron-ore localities with regard to Calcutta.

with regard to Calcutta, the principal points of which at present are Gurumaisani, Noamundi, Gua and Manharpur (Manoharpur).

The accompanying geological map (Plate 31) on the scale of 1 inch=4 miles has been reduced from the one inch to the mile maps which were used during the survey.

No attempt is made in this memoir to give an account of the following iron-ore deposits, also situated in the province of Bihar and Orissa, and the subject at intervals of exploitation for modern iron-smelting enterprises :—

(1) The iron-ore deposits of Mayurbhanj State still being worked by the Tata Iron and Steel Co.[1]

(2) The deposits of magnetite in magnesian schists near Turamdih in Dhalbhum formerly worked by the Bengal Iron and Steel Co.[2]

(3) The deposits of hematite and magnetite associated with ferruginous schists at Hakigora in Dhalbhum, formerly worked by the Bengal Iron and Steel Co.[3]

[1] P. N. Bose, *Rec. Geol. Surv. Ind.*, XXXI, pp. 168-170, (1904). T. H. Holland and L. L. Fermor, *Rec. Geol. Surv. Ind.*, XXXIX, pp. 108-113, (1910), and subsequent Quinquennial Reviews of the Mineral Production of India.

[2] L. L. Fermor, Director's General Report for 1908, *Rec. Geol. Surv. Ind.*, XXXVIII, p. 41, (1909).

[3] *Ibid* p. 42.

(4) The apatite-magnetite-deposits of Dhalbhum, which have been used as a source of phosphoric iron-ore at Kulti by the Bengal Iron and Steel Co.[1]

Accounts of these will be found in the papers cited, and in addition La Touche's annotated 'Index of Minerals of Economic Value' forming Part I B of his 'Bibliography of Indian Geology and Physical Geography', may be consulted[2] for a summary of our knowledge of other iron-ore deposits in Bihar and Orissa.

Acknowledgments.

I am indebted to the various iron-mining companies and to their local managers for help and hospitality when visiting their properties, and also for much information which they have supplied and permitted me to incorporate in this memoir. I am especially indebted to the Bengal Iron Company, Ltd., the Tata Iron and Steel Company, Ltd., with their present geologist Dr. F. G. Percival, and their late geologist Mr. E. Parsons, the Indian Iron and Steel Company, Ltd., and Messrs. Bird and Company, including their present geologist Dr. E. Spencer, and Mr. H. Day.

I also wish to express my thanks to the district officials, amongst whom I should mention Mr. J. E. Scott, O.B.E., I.C.S., Mr. W. H. Lewis, I.C.S., Mr. J. Dain, C.I.E., I.C.S., Deputy Commissioners at different times of the Singhbhum district; also to numerous Forest Officers of the Singhbhum district, amongst whom I should mention the late Mr. A. M. Grieve, and Mr. J. H. Lyall.

Also to the different Superintendents of the Kolhan Government Estate, amongst whom I should mention Mr. E. A. Oakley, Mr. W. Kelly and Mr. H. Coles, who were in charge at different times during my tours in Singhbhum, and to Mr. J. Dixie who was District Engineer at one time.

My thanks are also due to the Ruling Chiefs and officials of the Feudatory States that I visited.

A number of the analyses given in the text were supplied by the iron-mining companies, and to them I tender my thanks.

[1] L. L. Fermor, Director's General Report for 1918, *Rec. Geol. Surv. Ind.*, L, p. 14, (1919).

[2] Pages 240 to 245.

Visit to Lake Superior.

In 1927, I visited the Lake Superior iron-ore area in the United States of America with the idea of seeing how the Indian deposits compared with the deposits there; more especially to compare the soft powdery hematite, which often occurs below the hard hematite in India, with the soft ores of the Mesabi range in Minnesota.

I received great assistance, and much information, from Mr. W. L. Tinker, Secretary of the Lake Superior Iron Ore Association, and from Mr. W. P. Chinn of Messrs. Pickands, Mather and Co. (agents for a number of the iron-mines), in drawing up a programme of tour, arranging for letters of introduction, visits to mines, works, etc. The officers of the Oliver Iron Mining Co., the M. A. Hanna Co., Messrs. Pickands, Mather and Co., and numerous officers of other companies did all they could to make my tour a success, and were always willing to arrange for my going over mines and works, and to give me any information and assistance that they could. I am also indebted to Messrs. Crowell and Murray, Cleveland, Ohio, and Messrs. Skilling's *Mining Review*, Duluth, Minnesota, for some of the information and figures quoted. A description of this visit was published in 1929.[1]

History of the Investigation.

Almost from the commencement of the Geological Survey of India, the pages of its publications contain numerous references and descriptions of the iron-ores of India, but it was only comparatively recently that serious attention was paid to the iron-ores of the area under description.

Mr. P. N. Bose[2], in 1904, first described the iron-ores which he had discovered in Mayurbhanj State and brought them to the notice of Mr. J. N. Tata.

The Singhbhum deposits were first discovered by Mr. R. Saubolle, a prospector who in 1907 brought specimens of extremely good quality limonite from Notu Buru and Pansira Buru to the office of the Geological Survey of India for identification. Messrs. Martin & Co., Ltd., the managing agents of the Bengal Iron & Steel Co., Ltd.,

[1] H. C. Jones, *Trans. Min. Geol. Inst. Ind.*, XXIV, pp. 176-201. (1929).
[2] P. N. Bose, 'Notes on the Geology and Mineral resources of Mayurbhanj', *Rec. Geol. Surv. Ind.*, XXXI, pp. 168-170, (1904).

(now Bengal Iron Co., Ltd.), investigated the occurrence and took up a mining lease of the Pansira Hill and commenced mining operations in 1910. This was the forerunner of the several areas which have been located, and some of which are now being mined for iron-ore. During the war there was a big demand for Indian iron and steel and this led to an increased demand for iron-ore. Prospectors in the area under description had discovered a number of new iron-ore bodies, and numerous applications were made for prospecting licenses and mining leases. The District officials knew practically nothing of the nature or extent of the iron-ore deposits, and I was deputed in 1918-19 to start a geological survey of the area, which was to form part of the general geological survey of Bihar and Orissa; but the demands for leases became so urgent that I was instructed in 1921 to obtain a rough idea of quantities of iron-ore in the area, so that the local and other officials would have some idea of what they were leasing. The result of my survey of the area, carried out in the cold weathers of 1919-21, showed that these iron-ore deposits are remarkable for the enormous quantities of extremely rich ore they contain and that they will take a place amongst the largest and richest iron-ore areas in the world.

Most of the work connected with the estimation of iron-ore was originally carried out by myself in 1919-20 and 1920-21, but during field-season 1920-21, Capt. C. T. Teychenné accompanied me for a short time, and was responsible for some of the estimates of quantities of iron-ore available in the Ganda Marden range, west of Keonjhargarh, and some other areas in the Keonjhar State.

Dr. J. A. Dunn worked on the boundaries of the Iron-ore series and the granitic rocks during the latter part of 1921-22, and during season 1922-23, after which he carried on work in North Singhbhum and in the Ranchi and Manbhum districts; he has described this latter work in Volume LIV of the *Memoirs, Geological Survey of India.*

Dr. M. S. Krishnan worked with me for season 1924-25 in Bamra State, and then for the two seasons 1925-26 and 1926-27 in the Keonjhar State with the excellent new maps that had been made by the Survey of India; he made separate estimates of the quantities of iron-ore in a large number of the deposits of that State.

Dr. L. A. Narayana Iyer worked with me during season 1923-24, and during the early part of 1924-25. During parts of 1925-26 and 1926-27, he mapped most of the granitic area with its dykes

in sheet 73 F/16. During most of these seasons, however, he worked with Dr. Dunn.

In December, 1929, Mr. G. V. Hobson spent about three weeks mapping a small area in the Keonjhar State that had been left blank between my own work in the Singhbhum district on the west, and that of Dr. Krishnan in the Keonjhar State to the east.

Physical Aspects.

The area under description may be roughly divided into two parts. The eastern part, consisting of the Singhbhum plain, is made up mainly of granite with small areas of schists and shales. The monotony of the plain is broken to a certain extent by small rugged hillocks or ridges formed of dolerite or other rock. This plain is well populated and very largely cultivated, the principal crop being paddy (rice). The western part, in which most of the iron-ore occurs, consists of a mass of steep forest-covered hills, rising to a height of about 3,000 feet in the area known as the Saranda *Pir*, and to over 3,000 feet in the Bonai and Keonjhar States.

The hills of the area form part of an old peneplain, the general height of which is about 2,500 feet above sea-level. The general nearly level character of the tops of the hills in south-west Singhbhum and the adjoining States is very marked when observed from the top of almost any of the higher hills, such as those near Gua.

The view from the top of most of the hills in the Saranda *Pir* is very fine; a confused mass of hills covered with varying shades of green of the *sal* and other forest trees, and with the occasional silver gleam of a stream winding its way through the hills.

The shales and soft sandstones of the Iron-ore series form part of the low land and this is usually much cut up by small streams. When the bedding of the shales and sandstones is fairly flat, the country is generally undulating, a marked feature of this country being the fragments of white quartz which are the remains of numerous quartz veins which occur in the shales.

When the bedding is fairly steep, the shale country is much cut up into narrow ravines, but the shale hills are generally marked by rounded contours.

In the north-west of the Kolhan adjoining Gangpur State, where the shales become phyllitic in character, these ravines are much more marked and are dependent to some extent on the strike of the rocks.

The granitic country is generally flat, and typical granite tors are not common, but are seen to a small extent north of Champua in the south of Singhbhum.

The series of dolerite dykes which have penetrated the granitic rock often occur at the surface as a series of long ridges, say up to a quarter of a mile or more wide, which often rise one hundred feet or more above the granitic surface, and which can be traced for many miles, to small dykes represented at the surface by little more than a few rounded boulders. The line of these dykes is often marked by scrubby vegetation.

Topography.

The area in which the iron-ore bodies occur consists mainly of a mass of hills and ridges largely covered with reserved and protected forests of *sal* trees. The small valleys between the hills usually have a good layer of soil, which is often cultivated; but the hilly area is rather sparsely inhabited. This may be partly due to the damage done to crops by elephant, deer, pig and other wild animals.

The hills rise about 1,000 to say 1,500 feet above the valleys. To the north-east of the iron-ore area stretches the granitic plain of Singhbhum. The general level of the Singhbhum plain in the south is about 800 feet and the highest point of the main iron-ore range in Singhbhum is 3,038 feet and occurs near the old village of Sasangda (22° 07′ : 85° 18′). The main iron-ore range, running from Ghatkuri in a S. S. W. direction, acts as a watershed over most of the area, but it is cut through at two points. Good sections of the rock are seen in these gorges and one realises in these places the wonderful folding that some of these rocks have undergone. An example of this is seen in Plate 18.

Drainage.

The general drainage of the area is to the north-east, the principal rivers being the Karo, the Koina and the Baitarani, the source of each of these rivers being in the area worked over. These streams are usually beautifully clear, and carry water all the year round. The Saranda *Pir* is well watered at all times, but the small streams in south-east Singhbhum, dry up soon after the end of the rains and the villagers are often dependent on water which they have stored up by putting up small embankments in the stream bed. When these reservoirs dry up, they depend largely on water obtained by digging holes in the stream bed.

Climate.

The climate is delightful during the cold weather from about November to the middle of March, the mornings and nights during December and January being bitterly cold. It begins to warm up in March, and in April, May and early June, the temperatures can be very high, but the air is fairly dry. Occasional thunderstorms, however, during these months give a certain amount of relief. The rainfall is about 53 inches a year in the plains and 64 inches in the hilly tracts, of which about 90 per cent. falls between June and October. The area is generally looked on as being rather unhealthy, and the period, say September to November, following the end of the rainy season is usually very feverish. Blackwater fever breaks out in certain parts, usually about this period.

Fauna and Flora.

The local inhabitants, mostly *Hos* and *Kols*, with their bows and arrows are keen *shikaris*, and small game except pea-fowl and jungle fowl is comparatively scarce. In the hilly tracts big game is often abundant, numerous herds of bison and sambhar occur in the Saranda *Pir ;* but owing to the thick forest and the nature of the country, one may go for a long time without seeing any animals. Elephant are often met with in Bonai, Keonjhar and in the Kolhan Government estate in Singhbhum, and they do a tremendous amount of damage to crops. Tiger are very common in the western part of the area, especially in the Saranda *Pir* and in the adjoining parts of Bonai and Keonjhar States. Panther are fairly common, and bear occur in large numbers throughout the area. The latter often being met during the progress of survey work, and are commonly seen during the *mahua* season, making for the *mahua* trees. Wild pig are numerous and do much damage to crops.

Fauna.

The reserved forests consists mainly of *sal* (*Shorea robusta*) which is largely cut and worked up into railway sleepers. Dr. Fermor has noticed that *sal* trees do not grow, or at any rate only in very stunted form, when the soil is from an ultrabasic rock. Bamboo (*Dendrocalamus strictus*) grows abundantly on the epidiorite type of rock. *Sabai* grass (*Ischaemum augustifolium*) and spear grass (*Audropogon contortus*) are very

Flora.

abundant in the early part of the cold weather and make geological work difficult, tedious and uncomfortable.

Maps.

The geologically coloured map (Plate 31) is reduced from the original field-maps on the scale of one inch=one mile. The maps used by me when I made the original estimates of quantities of iron-ore in Singhbhum were the topographical sheets on a scale of one inch=one mile, which were published about 1914. These were supplemented by Forest Survey maps of certain areas, on a scale of four inches=one mile, and which I found very accurate and extremely useful for the purpose required.

The maps used in the original estimates of iron-ore in Bonai and Keonjhar States were on a scale of one inch=one mile, and were published about 1860-62. They were uncontoured and not at all satisfactory for the purpose, but being the most suitable that were available, I had to make the best of them. About 1925, new one inch to the mile maps of Bonai and Keonjhar States were published, and these were used both by Dr. Krishnan and myself.

CHAPTER II.

GENERAL GEOLOGY AND GEOLOGICAL HISTORY.

General Geology.

The rocks of the area are shown by Dr. J. M. Maclaren in his map and account of 'The Auriferous Occurrences of Chota Nagpur, Bengal', as Dharwarian.[1]

Dr. Fermor in 'The Manganese-Ore Deposits of India', referring to the area south of Chaibassa, says[2] :—

'The but slightly metamorphosed character of these sandstones and grits and their gently rolling disposition would be more consistent with a Kadapah than a Dhárwár age for them; but I think that in this case we have to deal with some Dhárwár sediments that have escaped being much folded and have therefore been but slightly metamorphosed.'

Dr. Fermor in 1919 put forward the following general classification of the Archæan rocks of the Chota Nagpur type[3] :—

(1) Oldest gneisses and granites—not yet certainly identified.

(2) Dharwar sediments and contemporaneous lavas.

(3) Oldest gneisses re-melted—now post-Dharwar and probably forming a considerable portion of the 'fundamental gneiss.'

(4) Post-Dharwar intrusives :—

(*a*) Peridotites and other ultrabasic rocks.

(*b*) Granites and pegmatites.

(*c*) Epidiorites (altered dolerites and gabbros).

Towards the end of the field season 1920-1921, I found that there were two groups of sedimentary rocks with contemporaneous lavas which were separated by a marked unconformity, both of which in

[1] *Rec. Geol. Surv. Ind.*, XXXI, (1904).
[2] *Mem. Geol. Surv. Ind.*, XXXVII, footnote p. 619, (1909).
[3] *Proc. Asiatic Soc. Bengal*, *N. S.*, XV, p. clxxvii.

the past had been included in the Dharwar rocks of this area. This I confirmed and worked out during the following field season, and in my progress report of the season's work suggested[1] that the name 'Dharwar' should be retained for the older group, which consists mainly of schists and quartzites of typical Dharwar aspect, and that the younger rocks should be termed the Iron-ore series until further work decided the age of these beds. The term 'Iron-ore series' was used by Mr. E. Parsons and myself in discussions, and as a convenient field term for a considerable time, and in his description of Indian iron-ores in 1922[2], he has used the same term. This term will be used in this memoir in the form 'Iron-ore series'.

Dr. M. S. Krishnan[3] also reports the Iron-ore series in Keonjhar State as overlying the Older Dharwars unconformably.

The lower beds of this younger group in South Singhbhum consist of sandstones, conglomerates, limestones, shales, and a banded hematite-quartzite, all of which are of typical sedimentary aspect and almost un-metamorphosed, and were at that time considered to be possibly of post-Dharwar age. Dr. J. A. Dunn[4], however, has traced these almost unaltered sediments into North Singhbhum and has stated that they become very folded and take on a gradually increasing metamorphic character both along the strike and across the dip, until, to the north and west of Chakradharpur, the rocks become typical metamorphic schists whose lithologic characters are identical with those of the Older Metamorphics. He states that the Iron-ore series should be considered as part of the Dharwar system, and puts forward the following classification:—

5. Newer Dolerites (uralitised in places).		Cuddapah or earlier.
4. Granites and granite-gneisses.		Archæan.
3. Ultrabasic igneous rocks.		
2. Iron-ore series with the Dalma volcanic flows at the top.	Dharwar.	
1. Older Metamorphic series.		

[1] *Rec. Geol. Surv. Ind.*, LIV, p. 41, (1922).
[2] *Mining Magazine*, XXVI, (1922).
[3] E. H. Pascoe, General Report for 1926, *Rec. Geol. Sur. Ind.*, LX, p. 77, (1927).
[4] *Mem. Geol. Surv. Ind.*, LIV, p. 11-12, (1929).

If we take it for granted that Dr. Dunn has proved that the rocks of the Iron-ore series are of Dharwar age, then my classification of the rocks of South Singhbhum is as follows:—

Newer Dolerite dykes and sills.		Cuddapah.
Ultrabasic igneous intrusive rocks.		Archæan.
Granitic rocks.		
Shales with epidiorites and ash beds.	The Iron-ore series (Newer Dharwar.)	
Banded hematite-quartzite with iron-ore bodies.		
Shales with occasional thin sandstones and calcareous bands.		
Limestone (in places).		
Purple sandstone with a basal conglomerate in parts, and sometimes with bands of conglomerate.		
Hornblende- and mica-schists and quartzites.	Older Dharwar.	

I have placed the ultrabasic rocks above the granitic rocks, as I have found several cases where they appear to be intrusive into the granites.[1]

Geological History.

The Older Dharwar rocks are the most ancient rocks found in the area, and they consist of quartzites and schists of sedimentary origin, and hornblende-schists of igneous origin. These rocks have been subjected to enormous dynamic forces, which have folded, and tilted them in all directions, during which they have been highly metamorphosed, and have developed marked schistosity.

It seems probable that most of the metamorphism of these rocks took place before the later granitic intrusion, because that intrusion has produced very little metamorphic effect on the Iron-ore series of South Singhbhum. After these Dharwars had been partly denuded away and the area had become a marine area, the Iron-ore series, consisting mainly of shales and sandstones with limestone and conglomerate bands and with a basal conglomerate in parts, was laid down on their upturned edges. During the time these beds were being laid down, there seems to have been a certain amount of up-and-down movement of the sea bottom, as the basal conglomerate does not appear everywhere and bands of conglomerate and sandstone also occur at various horizons in the Iron-ore series. During this period of sedimentation, there were further periods of

[1] Both Dr. Dunn and I regard the ultrabasic rocks of Singhbhum as definitely older than the granitic rocks. Mr. Jones may have found an ultrabasic suite of different age from the ultrabasic rocks of Jojohatu and elsewhere in Central and North Singhbhum; Dr. Dunn expresses the view, however, that the dyke-like masses of ultrabasic rock occurring in the granite of Bonai may be large elongated inclusions or roof-pendants.—L. L. Fermor.

igneous activity, more especially in North Singhbhum when the Dalma volcanic series was extruded. In South Singhbhum various basic lavas and tuffs occur interbanded with the shales of the Iron-ore series. After the Iron-ore series had been laid down, the area was again uplifted, and this was followed by a granitic intrusion which broke up and absorbed large quantities of the Dharwar rocks. This granitic intrusion raised rather than broke up or bent the rocks of the Iron-ore series to any great extent, but a certain amount of absorption and penetration did occur, as can be seen at Simjang (22° 26′ : 85° 45′) and other places. The purple sandstone, the limestone and the shale are all found in contact with the granite at different places, which seems to indicate that the lower beds in some parts had been largely absorbed, but the magma seems to have been fairly cool. The shales have a general dip away from the granitic mass, and possibly some of the folding and faulting noted is due to this intrusion. Following this granite intrusion was a period of considerable earth movement, during which the ultrabasic rocks were possibly intruded.[1] These earth movements resulted in the granite area being traversed by a big series of fractures running north-north-east to south-south-west with a minor series running north-north-west to south-south-east. Along the fractures, basic igneous rock was intruded and formed the Newer Dolerite dykes, which are such a marked feature of the area to-day. In the Iron-ore series these fractures seem to run along the strike of the beds, and have given rise to a series of strike faults, along some of which doleritic rock in the form of sills was intruded. In this Iron-ore series much of the basic rock occurs in the form of sills and laccolites. At the same time, or very shortly after this period of basic intrusion, there was another period of earth movements, which caused extensive faulting in the west of the Kolhan Estate, and in Bonai State. These faults are sometimes represented by lines of fault-breccia, in which the basic rock occurs both as fragments of the breccia, and also acting as a cementing material to the fragments.

The ultrabasic rock is certainly earlier than the Newer Dolerite dykes, as near Rangra (22° 03′ : 85° 09′) in Bonai State, a basic dyke is seen cutting across a patch of ultrabasic rock. The ultrabasic rock is certainly intrusive into the Iron-ore series and apparently also into the granite.

[1] But see footnote on page 178.

CHAPTER III.

OLDER DHARWARS.

This series of rocks is the oldest in the area, and is found as small isolated, irregular, highly metamorphosed patches, included in and caught up by the granitic rocks. The rocks often weather at much the same rate as the granite, and as they are often soft schists, the boundaries of the patches are often extremely doubtful, as they are often covered by a layer of soil. These rocks are also found overlain by the basal beds of the Iron-ore series. This is indicated in the sketch sections, Figs. 2 and 3 on page 183. At times these patches are too small to be mapped, and as noted above, the boundaries of these Older Dharwars and the granite is often hidden, and therefore the boundaries in some cases may be approximate on the map.

No sequence could be made out in this group as the rocks occur in small isolated patches and whisps, which have been caught up, tilted, and in some cases penetrated by the granite. This is shown in Plates 13 and 14. Dr Dunn[1] records a case 2½ miles south of Siringsia (22° 22′ : 85° 43′), where the hornblende-schist intrudes the Dharwar quartzite as a dyke, and he therefore considers the quartzites as the earliest representatives of the Dharwars.

The rocks are generally quartzites, hornblende-, mica- and chlorite-schists. The dip of these rocks, owing largely to earth movements, varies considerably, but seems to be generally in a north or north-west direction. They are often very highly folded, and sometimes are nearly vertical. Quartz veins sometimes occur in the schists.

The quartzites and sandstones of this series are usually hard compact rocks breaking with a conchoidal fracture. They usually resist weathering better than the surrounding granite, and then stand up as small hillocks and ridges. The quartzite varies in colour from white to pink, brown or green, and occasionally has a red jaspery appearance. Under the microscope are seen irregular rounded grains of quartz cemented together by secondary silica, usually white in colour. A

Quartzites.

[1] Manuscript report, *Geol. Surv. Ind.*, p. 6, (1922).

little magnetite partially altered to hematite is usually present. Veins of secondary quartz of a white colour are common in the quartzites.

A hard green fine-grained quartzite from near Buru Siringsia (22° 19′ : 85° 41′) is found to consist of small angular quartz grains that have suffered from crushing, with numerous small plates of the green mica, fuchsite.

Quartz-sericite-schists.

Quartz-sericite-schists are fairly common, and one from the east of Buru Siringsia is a pale greenish medium-grained rock which under the microscope is seen to be made up of very irregularly shaped quartz grains, which are much fractured and broken up. The groundmass and the cracks in the quartz grains are filled with fine-grained sericite. A similar rock occurs underlying the Iron-ore series near Mungra (22° 15′ : 85° 39′).

These quartzites in some cases have been largely broken up by earth movements, and later cemented by veins and stringers of quartz, so that in some cases, as in the hills east of Jahirpi (22° 15′ : 85° 42′), the quartzite is almost entirely represented by this secondary quartz.

Hornblende-schists.

The hornblende-schists are usually medium-grained, dark, greenish black rocks which weather at much the same rate as the granite and therefore make no surface feature. They are often caught up by the granite, which in some cases has forced veins and stringers of granitic material into them. The rocks consist mainly of hornblende and felspar, and one type collected from south-west of Nurda (22° 20′ : 85° 44′) is a dark green, medium-grained, tough schist, which the microscope shows to be made up almost entirely of green hornblende with fine granules of magnetite. Another type collected from the west of Patahatu (22° 13′ : 85° 41′) is a dark, greenish grey, schistose rock which is found to consist of hornblende, nearly colourless pyroxene (diopside), some quartz and kaolinised felspar. Associated with the hornblende-schist at this locality is a quartz-epidote-rock. It is a bright yellow-green, fine-grained rock, and is made up of granular quartz and epidote.

Chlorite-schists.

The chlorite-schists are usually weathered and decomposed at the surface and therefore do not seem to be abundant. In the Deo river, near Mungra (22° 15′ : 85° 39′), bands of chlorite-schist occur in the hornblende-

schist. The rock when examined with the microscope shows pale green chlorite with a few granules of magnetite.

Mica-schists.

The mica-schists when exposed are almost always very decomposed. They are usually coarse-grained and very friable. They consist of muscovite and biotite with some quartz and felspar.

Steatite-schists.

Steatite-schists are seen associated with hornblende- and chlorite-schists to the south-east of Bara Mirgilindi (22° 17′ : 85° 42′). The strike and dip of the schists at this point is somewhat variable, but they seem to strike generally north-west to south-east and dip about 40° to the south-west. Steatite-schists also occur on the north side of the big valley, one mile south-west of Murda (22° 20′ : 85° 44′). The rock is pale grey in colour, and has a soapy feel. When examined with the microscope, it is found to be made up of granules and fibres of micro-crystalline steatitic material. Another occurrence is near Suiamba (22° 02′ : 85° 09′) where the rock is grey in colour, fine-grained and has a soapy feel. Under the microscope the rock is seen to be made up of minute steatitic material.

CHAPTER IV.

THE IRON-ORE SERIES.

General Geology.

Relation to other rocks.

The group of strata known as the Iron-ore series, has in the past been included in the rocks of Dharwar age, but as noted on page 176, there is no doubt that the term Dharwar in this area has in the past included two distinct sedimentary groups. This is well seen in the Deo river near Mungra (22° 15′ : 85° 39′), about two miles north of Jagannathpur. The basal bed of the Iron-ore series at this point is a conglomerate about eighteen inches thick, and it is seen resting in a nearly horizontal position on the steeply inclined Older Dharwar hornblende-schists and quartzites, and also on the granitic rocks. The following sketch section (Fig. 2) across the river at this point gives it in diagrammatic form. The granite has caught up and penetrated the schists in all directions. Plates 13 and 14 show this, and Plate 15 shows the nearly horizontal conglomerate resting on steeply inclined Older Dharwar rocks, which consist of hornblende-schists and quartzite.

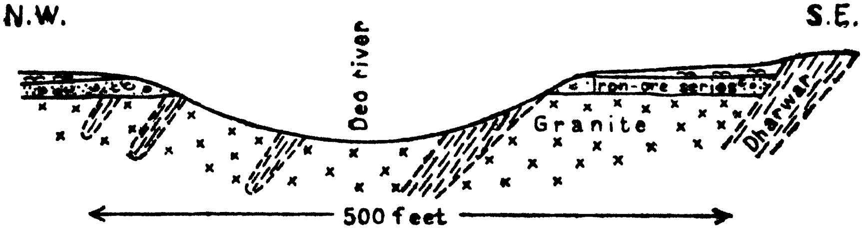

FIG. 2.—Sketch section, Deo river, just north of Mungra village.

A somewhat similar section is seen in the hills south-east of Kochra (22° 16′ : 85° 40′), and is shown diagrammatically in Fig. 3.

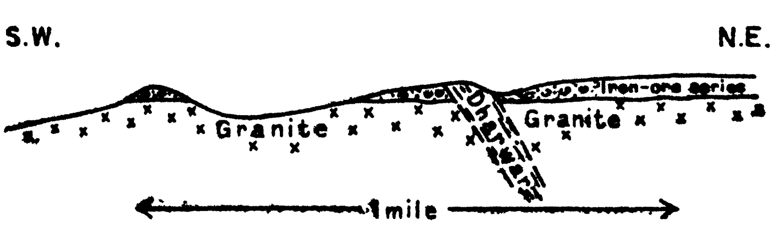

FIG. 3.—Sketch section, three-quarters of a mile south-east of Kochra.

The Iron-ore series in South Singhbhum has been divided as follows, No. 1 being the oldest bed:—

5. Upper shale with epidiorites and ash beds.
4. Banded hematite-quartzite, with iron-ore.
3. Lower shale, with occasional thin sandstone and calcareous bands.
2. Limestone.
1. Purple sandstone with conglomerate in parts.

Comparison with North Singhbhum.

Dr. Dunn[1] has described the Iron-ore series in North Singhbhum, but states that no equivalent divisions of the series can be made out there. He states that this is partly due to the severity of the earth movements which have taken place in the north; but the essential reason is that in South Singhbhum the period was one of practically continuous sedimentation, whilst in North Singhbhum acute vulcanism took place during the latter part of the period.

There was a certain amount of volcanic action in South Singhbhum during the latter part of the period when the upper shales of the Iron-ore series were being laid down, and it was during this time that basic rock was poured out and ash beds laid down.

Although the divisions shown above are fairly well marked, they are by no means absolutely constant; shale beds, for example, occur at times in the lowest purple sandstone; sandstone bands also occur in both the lower and in the upper shale bands. These, however, are usually thin and impersistent, and too small to be mapped. The upper and lower shales are very similar in lithological character, and it is very difficult to distinguish between them, except when in contact with the banded hematite-quartzite.

Folding and faulting.

The beds of the Iron-ore series immediately to the south of Chaibassa (22° 33′ : 85° 48′) are little disturbed, and have a fairly regular dip and strike. Near the granite boundary to the south of Chaibassa, the basal beds of the Iron-ore series dip gently away from that boundary. To the west of the Karo river, however, they have been considerably disturbed, but have a general N. N. E. to S. S. W. strike, and dip generally in a W. N. W. direction at a high angle, about 70°. Acute folding is common, and is often seen in the

[1] *Mem. Geol. Surv. Ind.*, LIV, p. 17, (1929).

banded hematite-quartzite. It occurs also in the shales, but owing to their softer nature examples of this are not so often seen.

Faulting in the shale country is often indicated by numerous slickensided surfaces, but it is impossible to trace the faults for any distance, owing to the soft nature of the rocks, and to the covering of soil which is usually present.

The general structure of the Iron-ore series in the southern part of the iron-ore area is an asymetrical synclinorium pitching towards the north. This is well seen towards the south end of the iron-ore area in Bonai State. The west arm of this synclinorium is slightly overfolded and dips at about 70° towards the west, whilst the east arm is complicated by folding, but has a general dip of, say, 45° in a westerly direction. This synclinorium pitches towards the north. Near the Singhbhum-Keonjhar boundary and towards the north, the structure becomes obscure owing to excessive folding, faulting, and largely to the covered nature of the ground. The structure is generally only to be made out where the banded hematite-quartzite is exposed, as the shales are too soft to give continuous exposures, and they are usually covered with a mantle of soil.

The banded hematite-quartzite forms the back-bone of the main iron-ore range and stretches across country in a N. N. E. to S. S. W. direction from, say, near Gua (22° 13′ : 85° 23′) to just north of Chendongra (21° 43′ : 85° 06′), a distance of about thirty-five miles. This banded hematite-quartzite is in the west arm of the synclinorium and just north of Chendongra the outcrop bends round to the east and swings away to the north-east to form the eastern arm of the synclinorium. The outcrop of the banded hematite-quartzite in the east arm is much wider than in the west arm, owing partly to the flatter dip, but also to the more pronounced folding that has taken place. The newer shales rest conformably on the banded hematite-quartzite, and occupies most of the space between these two arms.

Metamorphism.

These rocks in South Singhbhum have been comparatively little affected by metamorphic action, but there is no doubt that as one proceeds from the south of Singhbhum towards the north and north-west, the shales become much more phyllitic in character, and were first referred to by me as the Upper and Lower slaty shales, as I first encountered these rocks to the south of Chakradharpur, Goilkera and Manharpur. In the south the rocks are typical shales, but from the neighbourhood

of, say, Chhota Nagra (22° 14′ : 85° 19′) and Marang Ponga (22° 14′ : 85° 14′), the rocks become distinctly phyllitic in character ; the original bedding in the shale often becomes obscured by an incipient cleavage and the bedding can only be determined by different coloured bands in the shale rock. To the south of Manharpur, chloritic phyllites are abundant.

CHAPTER IV.

THE IRON-ORE SERIES—*contd.*

The Purple Sandstone.

Over most of the area between Chaibassa and Jamda (22° 10′ : 85° 26′), the Iron-ore series shows very little disturbance, and usually has a low dip to the north-west. The basal bed of the series is a nearly horizontal well-bedded, purple-grey sandstone, sometimes showing ripple-marking, and varying in thickness up to about 80 feet; but in parts it becomes a very striking conglomerate, consisting of well-rounded and some angular pebbles up to two inches in diameter, of white or clear quartz, and bright red jasper, with a few pebbles of banded quartzite in a dark purple-grey, often ferruginous sandy groundmass. No granite pebbles were found in the conglomerate.

This basal bed is usually a moderately soft rock, but is less easily weathered than the underlying granitic rock, or the overlying limestone, and hence usually forms a low scarp or series of small hillocks which can be traced for many miles. The conglomerate is coarsely jointed at times in three directions nearly at right angles, which cause the rock to break up into large rectangular blocks which is well seen in Plate 15. This conglomerate is not always present as a basal bed and similar thin bands of conglomerate and coarse sandstones occur at different horizons in the purple sandstone, which shows that there was a certain amount of oscillation taking place in the level of the sea floor whilst these rocks were being deposited.

The sandstone is a moderately soft, medium to fine-grained rock of a purple-grey colour, with abundant white grains of kaolinised felspar.

The microscope shows it to be made up of well-rounded grains of quartz and felspar, each grain having a thin coating of hematite, and the whole being cemented together by silica and ferruginous material. The felspar is rather kaolinised, and a few grains of magnetite or metallic-looking hematite occurs.

The relation of this sandstone-conglomerate to the granite is striking, as the contacts are often practically horizontal and the beds conform generally to the granite surface.

Simjang.

It often appears as if it had been laid down on the granite surface, but the absence of pebbles of granite in the conglomerate and the gentle dip away from the granite is against

this. That a certain amount of absorption and contact metamorphism has taken place is seen in the exposure in the river valley just west of Simjang (22° 26′ : 85° 45′) (see Plate 16). Here nearly horizontal purple sandstones with thin conglomerate bands rest on the granite, but for a distance of about ten feet above the granite contact the sandstone has been altered to a pale grey colour and at the actual contact there is a thin quarter-inch to two-inch layer which has been recrystallised to a coarse granitic texture. The granite has also penetrated very slightly into the sandstone and appears to have been gradually absorbing it, whilst small patches of the sandstone-conglomerate are seen enclosed in the granite just below the contact. Plate 16 shows the thin layer of metamorphosed sandstone at the contact with the granite. This metamorphosed sandstone is much harder and paler in colour than the purple sandstone. Microscopic examination shows that the well-rounded character of the quartz and felspar grains have largely disappeared, owing to secondary silicification. Most of the hematite that occurs in the ordinary purple sandstone has also disappeared. An occasional flake of mica occurs.

The granitic rock near this point is a medium-grained greyish rock consisting of quartz, orthoclase, plagioclase, and muscovite. The granite at the contact seems to be a very similar rock but the muscovite seems to have been largely replaced by powdery hematite.

Granite penetrating Iron-ore series.

That the granite has in some cases penetrated the Iron-ore series to some extent, is well seen near the top of the small hill just west of the sixth milestone on the main road from Chaibassa to Jamda. Here the purple sandstone of rather pale colour, which rests on the granite, is seen to be penetrated by numerous granitic veins. Also near Bandijari (22° 26′ : 85° 41′), some four miles from the main granite–Iron-ore series boundary, is a small boss of granitic rock which seems to have pushed its way through the basal beds and into the lower shales of the Iron-ore series, and bent them at this point into a small anticlinal fold. It appears, however, that generally the granite lifted the Iron-ore series slightly, rather than forced its way through them to any large extent.

Overlying the purple sandstone comes a band of grey and purple limestone, which passes through calcareous shales to a great thickness of purple and grey slaty shales.

The sandstones often contain secondary veins and stringers of unfiltrated quartz, brought in by silica-bearing solutions.

CHAPTER VI.

THE IRON-ORE SERIES—*contd.*

Limestone.

The limestone, which is often cherty in character, is best exposed to the south of Chaibassa, where it occurs as a well-bedded rock along the Gomua river valley, dipping at a low angle to the north-west. Being comparatively soft, it has been largely denuded away, and is now seen as patches along the river banks and sides of the valley. Although there is a marked change in the character of the rock, the limestone is conformable to the underlying purple sandstone. It can seldom be traced over any great area, and often occurs as very small patches. There seems to be no doubt that these limestones are sedimentary, but whether they were formed organically, or by chemical precipitation is doubtful. In some places, such as west of Jagannathpur (22° 13′ : 85° 38′), the limestone seems to have been absent, as the overlying shales rest directly on the purple sandstone. The accual limestone has a thickness of about 40 feet, but it passes up into calcareous shales. The rock is usually very fine-grained, and varies from a massive to a flaggy, fragile rock. It is occasionally quarried and used for making lime, but it contains up to about 12 per cent. of insoluble matter, consisting of quartz, and chloritic material, and the rock is often cut up by thin quartz veins. The rock varies from a grey to a red-purple colour. and is often of a shaly or schistose character, containing thin films and layers of chloritic matter.

South of Chaibassa.

A specimen collected from near Kondoa (22° 24′ : 85° 44′) is a nearly white, granular, schistose rock which is found to be made up of minute elongated granules of calcite, with a little granular quartz scattered through the rock. Another specimen collected from the Deo river, about five-eighths of a mile north of Mungra (22° 15′ : 85° 39′), is an extremely fine-grained, pale greenish grey, compact rock, which shows thin partings of micaceous or chloritic substance. This, when examined

Kondoa.

with the microscope, is found to be similar to the rock which was collected at Kondoa, but the grains are extremely minute. A specimen collected from just north of Simjang (22° 26′ : 85° 45′) is of the purple and rather schistose variety, and one from the hillock near Lipuabassa (22° 27′ : 85° 46′) is rather a gneissic-looking rock, consisting of white granular patches with irregular bands and films of dark grey micaceous or chloritic substance. This rock is found to be rather coarser-grained and more siliceous than those previously described. It also contains some powdery magnetite altering to hematite. The rock appears to have undergone a certain amount of strain, which has resulted in the breaking up of some of the calcite into rough cleavage rhombs, which have later been cemented by silica. This indicates that the quartz in these limestones is secondary.

Sosopi.

The limestone is well exposed near Sosopi village (22° 22′ : 85° 44′), where it forms a small hillock. The beds have a low dip of about 5° to the north-west. The rock varies in colour from reddish purple to greenish grey and is very impure, having grey chloritic material running through it in bands, and also scattered through it in irregular fashion, in addition to which there are numerous thin quartz veins. The limestone here is seen to be underlain by dark purple sandstone and conglomerate, having the same low dip to the north-west. Two exposures of the limestone are seen about two miles north-west of Jagannathpur (22° 13′ : 85° 38′) and the following sketch section (Fig. 4) gives an idea of the geological structure at this point, one of the exposures is a small inlier in a stream bed and has possibly been brought up by a small fold.

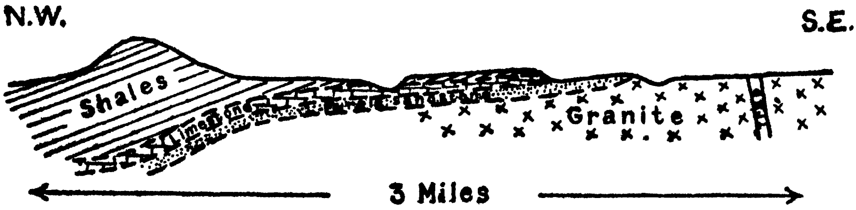

FIG. 4.—Sketch section north-west of Jagannathpur.

The average composition of the limestone is shown below as determined from about sixty samples collected and assayed by the

Tata Iron and Steel Co., Ltd., who kindly gave me the following figures :—

	Per cent.
CaO	50·58
MgO	0·53
Fe_2O_3 } Al_2O_3 }	0·88
Loss	39·78
Insoluble	8·29
TOTAL	100·06

The amount of magnesia is very low in all cases, and varied from a trace to a maximum of 0·88 per cent.

Small outlying patches of the limestone are occasionally found, but these appear to be more siliceous than the main exposure. In fact, limestone seems to be more abundant than is apparent from surface features. In the course of excavating a well at the Jamda District Board bungalow, a band of limestone was encountered, although there is no surface indication of any limestone near.

Banded limestone also occurs on the slope of a small hill about a mile due west of Jhargaon (22° 03′ : 85° 23′) in Keonjhar State. The hill consists of banded hematite-quartzite with a capping of hematite. This is the most southerly point at which limestone has been noted.

Between these two points, magnesian limestone has been encountered during prospecting and mining operations in the hills north-east of Bilkundi (22° 08′ : 85° 24′).

Another patch occurs as a band running across the bed of the Karo river, about a mile north of Ghatkuri (22° 18′ : 85° 24′). No actual contact with other rocks was seen, but the band has the usual north-east to south-west strike of the surrounding shales. Owing to the ground to the south-west being covered, the extent of the band could not be traced. The band shows no bedding, and it is rather massive. The rock is of a dark bluish grey colour, hard, fine-grained and compact, and is very much cut up with small quartz veins. Examined with the microscope, it is found to be made up of extremely minute grains of calcite with thin veins of white quartz. The rock effervesces briskly in cold dilute acid.

Ghatkuri.

The patch which occurs to the south of Patang (22° 23′ : 85° 24′) is much more extensive than the Ghatkuri patch. It is well seen in the bed of the Karo river, where it appears to be about 300 feet thick. Both above and

Patang.

below the limestone, there appears to be shale, and the one seems to gradually pass into the other without any sharp line of demarcation. The band strikes W. N. W. to E. S. E. and dips about 70° to the N. N. E. Following the band to the east, it forms a series of fairly high, somewhat rugged hills, and seems to gradually pass into shale. In parts the rock seems to be much bent. The limestone is very variable in character, but is mostly of a pale grey to a blue-grey colour, sometimes with darker bands of chert interbedded with it. The rock is very much cut up by small ramifying veins and veinlets of white quartz as can be seen in Plate 17, fig. 1. Some of the bands have small crystals of iron pyrites scattered through them. Towards the top of the hill the limestone seems to be less siliceous, and to contain fewer of the chert bands. The limestone is a magnesian one, and may be termed a dolomite. Under the microscope it shows the usual grains, which have a brownish tinge, fitted together along irregular lines, with variable quantities of chert in irregular shaped patches. Penetrating into these chert patches, rhombohedral sections of dolomite (? siderite) are sometimes seen, these often show zoning, a dark centre being surrounded by a clearer border. The silica forming the chert is an interlocking mass of quartz individuals of varying degrees of fineness and contains numerous minute needles. These zoned crystals penetrating into the cherty silica are seen in Plate 30, fig. 2.

The chert associated with this limestone is an extremely fine-grained, hard, compact, dark grey rock, with a few thin veins of white quartz. Under the microscope it is found to be made up of very fine grains of quartz, throughout which are scattered numerous extremely minute needles, and also some fair-sized, zoned rhombohedral crystals of ? siderite. This is shown in Plate 30, fig. 1. The quartz veins are clearer than the rest of the rock, but contain some of the dolomite, which however seems to have undergone some corrosion or solution, previous to the deposition of the quartz.

CHAPTER VII.

THE IRON-ORE SERIES—*contd.*

The Lower Shales and Phyllites.

The lower shales are well exposed between Chaibassa and Jagannathpur (22° 13′ : 85° 38′). It was noted in the last chapter that the limestone often gradually passes upwards into calcareous shales, which in turn gradually pass into true well-bedded shales. In addition to the calcareous bands, the shales often have lenticular bands of sandstone and conglomerate running through them. These sandstones are sometimes felspathic; they are usually thin, and can only be traced over a small area. The shales usually have a purple colour, but higher up in the group they become buff, grey and white in colour. Where the limestone is absent, as in the area south of Jagannathpur, the purple sandstone is overlain directly by the shales. There is a big thickness of these shales, but owing to the folding in the rocks which is largely hidden by the covering of soil, it is not possible to give a reliable figure of thickness. The shales are usually soft and finely laminated over most of the area under description, but in the north and north-western parts of the area, they often become phyllitic in character, and show an incipient cleavage which runs at a fairly high angle to the bedding. At times the shale is ferruginous, and when this is the case, it alters extensively at the surface, and more especially at the tops of hills, into lateritic material, which in some cases by further alteration have resulted in hematite iron-ore bodies, such as occur near Barabil (22° 07′ : 85° 24′), Guali (21° 59′ : 85° 17′), Bhadrasai (22° 03′ : 85° 24′), etc. The shales seldom make any surface feature, and usually occupy the low ground, except when they have been silicified or when capped by iron-ore or lateritic material which acts as a protective covering, and being soft they are easily disintegrated to form a layer of soil, so that in the low ground their structure and character are largely hidden by soil and debris.

Jointing and cleavage.

Jointing is sometimes very marked, and is well seen to the west of Pauinpi (22° 17′ : 85° 39′). The shales at this point strike in a east-north-easterly direction, and dip 18° to the N. N. W. Joints are seen running north

to south, and W. N. W. to E. S. E. and secondary joints running east to west.

The shales usually split along the bedding planes, but towards the north of the area, cleavage is also well developed, and often runs nearly at right angles to the strike and dip of the original bedding in the shales, as is indicated by the bands of different colour in the rock.

Calcareous shales.

Calcareous shales, occurring as a small anticline, are seen near Pasea (22° 17′ : 85° 35′). The ground is largely covered, but the southern arm of the anticline dips about 10° to the south-east, and the northern arm about 30° to the north-west. When viewed from a distance, the bedding is easily distinguished owing to the typical limestone weathering which the rocks take on; but when examined at close quarters, bedding is difficult to make out, because a very marked cleavage dipping to the north has been developed. The rock is extremely fine-grained, and is made up of fine, calcareous and argillaceous material with minute scattered grains of quartz.

In the river just S. S. W. of Chalpagara (22° 21′ : 85° 37′) a band of calcareous shaly material is exposed in the purple shale. It weathers like a limestone, but on breaking it, it splits into thin shale-like fragments.

A somewhat similar band, which is largely cut up by quartz veins, occurs in the Roro Gara to the east of Kariahatu (22° 28′ : 85° 38′).

There is a persistent calcareous shaly band high up in the shales near Jetia (22° 16′ : 85° 34′), and this can be traced for about eight miles in a north-east to south-west direction, after which it appears to die out. This is possibly the lower calcareous shale brought up by folding, but beyond some small local folds, the ground is too covered to make out the structure at this point.

Silicification of the shales.

Silicification of the shales is very widespread, and in some cases is certainly of later age than the Newer Dolerite dykes, and is evidently due to percolating siliceous solutions. This infiltration of siliceous material hardens the rock, and helps in the formation of hillocks. The purple shale near Daudonga (22° 23′ : 85° 43′), north of Dokata (22° 24′ : 85° 44′), shows this silicification particularly well, and the white quartz weathered out of the shale, which is found lying

all over the surface, is somewhat cellular, but retains to some extent the original shaly character.

Iron and manganese oxides in the shales.

Where conditions have been favourable, iron and manganese material has been brought in by meteoric waters, and replaced the shale material, and in some cases has segregated and formed deposits which are of some economic value. Such deposits are being worked west and south-west of Jamda (22° 10′ : 85° 26′), where the ore occurs in irregular lateritised patches in the shales. The laterite is often pisolitic, especially in the low hills west and south of Barabil (22° 07′ : 85° 24′), where it is worked as an ore of both iron and manganese.

Observations in various parts of the area, in mine workings, and in some of the borings at Noamundi, show that the shale at times gradually becomes more and more ferruginous, until eventually it passes into ore containing well over 60 per cent. of iron, and forms some of the important ore-bodies of the area. There seems to be no doubt that this ore has been formed by the action of meteoric waters carrying ferruginous matter, which has replaced the original shale material by iron oxide.

In the hills round Jamda there is a considerable amount of this replacement. The manganiferous replacement is indicated on the Jagannathpur-Jamda road, and on the Jamda-Jaintgarh road by the dark blue-black soil. Similar dark soil occurs in some of the cuttings along the Baraiburu-Gua road, and the hills between Baraiburu and Gua have been largely prospected for manganese-ore. This prospecting has revealed irregular segregations of mixed iron- and manganese-ore, from which a certain amount of first grade manganese-ore can be obtained by hand picking. Some of the mixed ore has been used by some of the mining companies as a manganiferous iron-ore.

CHAPTER VIII.

THE IRON-ORE SERIES—*contd.*

The Banded Hematite-Quartzite.

These banded rocks are very striking, and consist of interbanded layers in varying proportions of iron oxide, silica, and combinations of the two. The silica at times is crystalline, and at others is cherty. The chert, however, is not truly amorphous, but consists of fine interlocking grains of quartz. At times the silica is red and jaspery, and this red jasper often forms a large proportion of the rock. The iron oxide is usually hematite, but sometimes cubes and octahedra of magnetite and martite occur. It is in these banded rocks that most of the iron-ore bodies occur, and all gradations between them and iron-ore are found.

The similarity of these banded rocks to the jaspilites described by Dr. C. R. Van Hise and Dr. C. K. Leith in their monograph on 'The geology of the Lake Superior Region'[1], was early recognised by me, and this was confirmed when I visited the Lake Superior iron-ore area in 1927.

Mr. C. M. Weld in his description of [2] 'The ancient sedimentary iron ores of British India' says on page 436 :—

> 'These rocks range from pure dense quartzite on the one hand to pure massive iron ore on the other, every conceivable gradation between the two extremes being found at some point or other and often within the same area.'

Also on page 437 he says :—

> 'As a rule the ore-bodies do not have sharply defined walls : ore and siliceous banded ferruginous rocks grade one into the other.'

He also states on page 452 :—

> 'They are strikingly like the pre-Cambrian iron ores of Brazil. In fact, one is almost tempted to apply the Brazilian term *itabirite* to the quartz-iron ore beds, *jacutinga* to the laminated and micaceous ores occurring within phyllites, and *canga* to the surface accumulations of rubble-ore float and rich laterite.'

[1] *U. S. Geol. Surv.*, Mon. LII, (1911).
[2] *Econ. Geol.*, X, pp. 435-452, (1915).

Dr. Fermor[1] has suggested in describing similar rocks from the Jubbulpore district, that these rocks should be called banded hematite-jasper or banded hematite-quartzite.[2] Dr. Percival[3] has used the term banded hematite-jasper, but the term banded hematite-quartzite has got into such common usage in the iron-mining areas, and has been generally used in previous publications, that I propose to continue its use in this memoir.

Owing to their hardness, and partly to the comparative insolubility of the iron constituent, they resist weathering, so they are usually the most conspicuous rocks in the iron-ore area, and are often found forming steep cliffs, in which the bands of material of different colour, immediately attract one's attention. The bands, which are often very regular, vary from mere partings up to several inches in thickness, and in colour from white to lavender, grey, bright red, brown, black, etc. The difference in colour is due to the varying amount, and to the character of the iron present. The bands of hematite, although generally fairly regular, are found to thicken and thin out at times. The character of the siliceous bands varies considerably, some consisting mainly of chert of nearly white to brownish red colour, others compact dark grey to reddish grey, consisting of powdery magnetite and hematite in silica, others rather coarse-grained, and others containing abundant glistening crystals of magnetite or martite.

Minute octahedral crystals of magnetite occur in some of the bands, but they are almost always partly altered into hematite; however, in some cases, the crystals are non-magnetic, and the mineral is martite. The surface of a band which contains these crystals is often rough owing to the small shining crystals projecting from the weathered surface. When the crystals weather out, they are found as perfect little octahedrons in crevices or in the sand at the foot of a scarp. These rocks are often traversed by white quartz veins, and sometimes by thin veins of hematite.

When exposed at the surface, the siliceous bands may be leached away for say a quarter to half an inch, leaving the hematite bands standing out as ridges. The thin veins of

[1] *Mem. Geol. Surv. Ind.*, XXXVII, p. 808, (1909).

[2] He gives also an account of the microscopic characters of the hematite-jaspers of the Jubbulpore district, which can be usefully compared with the description of the similar rocks of Singhbhum given below. The similarity is very close. A photograph of a specimen of banded hematite-quartzite is given in Plate 9 of the same memoir.

[3] *Trans. Min. Geol. Inst. Ind.*, XXVI, p. 190, (1931).

hematite noted above as sometimes occurring in these rocks, are left joining the bands of hematite when the silica is dissolved away. The total thickness of the beds is difficult to estimate, but in the main range in Singhbhum, there must be about a thousand feet, whilst in Bonai State in the Korhadi river section, there is about a thickness of three thousand feet exposed.

The siliceous bands when examined under the microscope are found to consist mostly of crystalline quartz, usually extremely fine-grained, but of varying degrees of fineness. When sufficiently coarse, the quartz often shows undulatory extinction. Throughout the cherty silica are scattered occasional crystals of martite, powdery hematite, and flakes of red crystalline hematite. Some of the bands have a peculiar elongated speckling which is found to be due to crystals of magnetite or martite being arranged or growing in an elongated bunch, and being surrounded by a zone of clear quartz. The quartz round the iron oxide is generally coarser-grained than that forming the rest of the rock.

The red jasper bands vary from brilliant red to deep reddish brown in colour. Under the microscope it is found to be made up of grains of cherty silica full of powdery and minute flakes of brilliant blood-red hematite. An occasional crystal of magnetite or martite may be seen, but some of the bands show a considerable quantity of these crystals. This is well seen in Plate 30, fig. 3. Some of the chert bands are full of minute rounded granules.

Occasional rhombs of clear, rather coarse silica occur in these rocks, and probably represent pseudomorphs after some original carbonate in the rock. Similar occurrences have been recorded by Dr. P. A. Wagner [1] in his description of the iron deposits of the Union of South Africa, and Dr. Percival [2] has noted their occurrence in similar rocks at the Noamundi mine.

In my progress report[3] for 1918-19, I recorded the occurrence of rhombohedral crystals in some of the chert bands, and referred to them as dolomite. Dr. E. Spencer recently drew my attention to some of these crystals, which he had come across in some of the cherts of the iron-ore areas being worked by Messrs. Bird and Co. He states that from chemical analysis he has proved them to be siderite; he also showed me some thin sections of the rock which

[1] *Geol. Surv. Union South Africa*, Mem. 26, p. 61, (1928).
[2] *Loc. cit.*, p. 221, (1931).
[3] Manuscript report. *Geol. Surv. Ind.*, (1919).

he had heated for some hours, and in which the practically colourless siderite had been converted into black, metallic-looking, powdery iron oxide.

This suggests that some of the iron in these banded hematite-quartzites was originally in the form of iron carbonate.

A peculiar greenish variety of banded rock was noted near Sasangda. It consists of brownish ferruginous bands alternating with whitish grey and greenish bands. Under the microscope it is found to consist of bands of chert containing magnetite with an idiomorphic tendency, and thin crystal plates of hematite together with powdery hematite. The greenish bands are of chert, which is full of small granules having a greenish tinge.

The rock is often very contorted, and the bands of hematite, chert or jasper are seen to thin and thicken, or even to pinch out altogether, owing to this folding. Plates 18, 19 and 20, give an idea of the tremendous folding that some of these rocks in the area have undergone. At the apex of the folds, the rock in some cases opened up, and the spaces have been filled up with white quartz. Some of the minute folding or crumpling, which is very common in these rocks, and which can often be seen in hand-specimens, may be due to stresses produced locally, during the solution or replacement of the silica, and may not be due to the folding which produced the broad synclines and anticlines in this area.

Origin of the banded hematite-quartzites.

There is a considerable literature on the origin of similar banded hematite-rocks in different parts of the world, but none of the theories put forward have been generally accepted to explain the thin alternations of silica and iron oxide, and the work done in this area has not been sufficient to elucidate the problem. Dr. Percival[1] in his description of the iron-ores of Noamundi has given a summary of the various suggestions that have been made regarding the origin of these rocks.

It is generally accepted that the rocks are the result of chemical precipitation, but the conditions under which this precipitation took place is still uncertain, although it is generally assumed that the precipitation took place under marine conditions. The absence of indications of ordinary mechanical sedimentation in these rocks is noticeable.

[1] *Loc. cit.*, pp. 226-234, (1931).

The rocks at the present time, are undoubtedly in a different condition from that in which they were originally deposited. Similar rocks in the Lake Superior area have been shown to have been derived from banded sideritic cherts or sideritic shales. Dr. Wagner[1] says 'it appears reasonable to assume that the carbonate was siderite'.

In addition to the siderite, some of the cherts of the Lake Superior region contain minute granules of a pale green ferrous silicate known as greenalite.[2]

Bacteria and algae have been suggested as assisting in the precipitation of the iron and silica, but no indication of this has been noted in this area.

Some of the iron in these rocks may have been precipitated as ferric hydrate. This seems to have been the case in the hematite deposits of Brazil. It is stated[3] that 'Itabarite and bedded ore were formed together under similar conditions............ Iron oxide in ores and itabarite may have been deposited originally as (a) ferric hydrate, or as (b) iron carbonate. The first of these appears to be the more probable hypothesis.'

Most of the iron-ore of the area occurs in the banded hematite-quartzite rocks, and this will be described together with a discussion on its origin, in the section dealing with the iron-ores, but mention may be made here of the occasional occurrence of small lenses or patches of ore in these rocks. At times these are large enough to be worked by hand-mining, but it should be borne in mind during prospecting work, that a small lens of this type may give rise to a considerable quantity of hematite debris, which might give the impression of the presence of a large body of iron-ore.

[1] *Loc. cit.*, p. 64, (1928).
[2] *Loc. cit.*, pp. 165-168, (1911).
[3] *Econ. Geol.*, VI, p. 681, (1911).

CHAPTER IX.

THE IRON-ORE SERIES—*contd.*

The Upper Shales and Breccia-Conglomerate.

There seems to be very little difference in the character of the upper and the lower shales, and I have only been able to distinguish them when they are actually seen to be overlying or underlying the banded hematite-quartzite. These upper shales are of considerable thickness, and overlie the banded hematite-quartzite conformably, and seem to have undergone similar folding and tilting. These shales, as in the case of the lower shales, become metamorphosed in the northern and western part of the area under description, but nowhere do they become a true slate, as the easiest parting is usually parallel to the bedding; but an incipient slaty cleavage is seen in the rock. The rocks vary considerably, although the main mass is shale or phyllite, but the variations in the shale is often only due to colour. The colour of the shale is usually buff or reddish purple, but varies from white to grey, black, green, yellow, red, etc., and in texture it varies from a soft powdery kaolin-like clay to a hard siliceous rock, and from a typical shale to a glossy phyllite.

The shale contains a band of breccia-conglomerate, which is well exposed to the west of Tholkabad (22° 08′ : 85° 11′), but which seems to thin out towards the south-west, and also towards the north-east. The shales above this band of breccia-conglomerate contain sandstone or quartzite bands which are often conglomeratic. These sandy bands appear to be non-continuous, and can seldom be traced for more than a few miles.

Interbanded in these shales are contemporaneous beds of basic igneous rock and occasional ash beds, the minerals of both of which have been very largely replaced by silica.

The shales have a general north-east to south-west strike, and a steep dip in a north-westerly direction, but local folding is common.

East of Nawagaon (22° 03′ : 85° 14′), the main iron-ore range is made up of banded hematite-quartzite, which at the top of the range is partly altered and replaced by hematite. The lower slopes of both the east and west

Shales east of Nawagaon.

side of the range are shales. The lower shales of the Iron-ore series are seen on the east side of the range conformably underlying the banded hematite-quartzite. The banded hematite-quartzite is well exposed in the Lasara Gara gorge just to the south of Keonjhar (Kiri) Buru, dipping at about 70° in a north-westerly direction. The upper beds of the quartzite seem to contain more of the jaspery type than the lower beds seen on the top and east side of the range. This quartzite seems to be about seven hundred feet thick at this point, and is overlain conformably by a purple ferruginous shale. The shale varies in colour down the gorge, and gradually becomes greenish, and eventually at the west end of the gorge it is nearly black in colour. After the stream leaves the gorge, the shale becomes of a sandy ferruginous type, which on weathering gives rise to a sandy shaly lateritic material, in which contemporaneous sills or flows of much silicified basic igneous rock and occasional ash beds occur. The rocks in this gorge are fairly regular and uniform in dip, but a certain amount of slip and folding has taken place. The anticlinal and synclinal folds in the quartzite are not often seen on a large scale, but folding on a small scale is common and is often very sharp. Although there is change of dip and strike where the folds occur, these make practically no difference to the general strike and dip of the rocks as a whole. The quartzites form steep cliffs which give rise to waterfalls, which make part of the stream impassable. Still further to the west reddish purple and purple-buff-coloured shales occur, and these resemble to some extent some of the shales which occur on the east side of the range. Exposures of the shales are not good, and being of a soft nature, folds and slips are not often seen. That movement has taken place is evident from the slickensided surfaces that are occasionally exposed. Bands of cherty rock occasionally occur in these shales.

Carbonaceous shales.

An exposure of black carbonaceous shale was noted in a small cliff in the Jagretu Gara (Kariatuti Gara) to the south of Hendikuli (22° 12′ : 85° 08′). This carbonaceous shale is only exposed for a short distance, and is only a few feet thick. Where exposed it is overlain conformably by variegated sandy shale, which in parts has become so silicified that it may almost be termed a quartzite. The carbonaceous shale seems to be underlain conformably by greenish buff phyllitic shale, and seems to pass laterally into phyllitic shale.

Exposures of carbonaceous shales or phyllites seem to be much more abundant to the north of the area under description, and have been recorded by Dr. Dunn [1] in North Singhbhum, who has suggested that the carbon may have been derived from the combustion of volcanic gasses.

Dr. Krishnan [2] has also described similar carbonaceous rocks in Gangpur State, and Dr. Narayana Iyer has also recorded them in North Singhbhum.

The rock when handled has a somewhat greasy feel and soils the fingers, although the carbon constituent, which appears to be graphite, seems to form only a small proportion of the total rock. When burnt the ash has a grey colour.

Sandstone bands in shales.

Thin bands of sandstone or quartzite, usually of a pale greyish white colour occur in the shales, but they appear to be non-continuous, and can only be traced, at most, for a few miles. One of these bands near Dinda Buru crosses the main road about half-way between Tholkabad (22° 08′ : 85° 11′) and Tirilposi (22° 09′ : 85° 06′), and forms an impassable ridge for a large part of the three miles over which it is exposed. The rock is a massive, hard, compact, rather glassy-looking quartzite, and the bedding is rather indistinct, but the rock south of the road has the usual north-east to south-west strike and dips at about 60° to the north-west. North of the road the band swings round to the east, and has a dip of 50° to 60° to the north. The band occurs in a purple ferruginous shale and is about three hundred feet thick.

To the south of Kodalibad (22° 10′ : 85° 14′) the shales, which have the usual north-east to south-west strike and steep dip of about 60° to the north-west, become rather sandy in character, and the rock consists of thin alternating bands of shale and sandstone, which are too thin to show separately on the map. The shale is usually purple, buff or grey in colour, and the sandstone bands are usually white or pale-coloured, and are often somewhat felspathic. The sandstone is a rather soft rock, but resists weathering fairly well, and often gives rise to small steep cliffs; some of the sandstone is ferruginous, and this on weathering becomes buff or brown in colour. At times the sandstone becomes coarse-grained and conglomeratic in character.

[1] *Mem. Geol. Surv. Ind.*, LIV, pp. 45-48, (1929).
[2] *Rec. Geol. Surv. Ind.*, LXIII, p. 84, (1930).

At times the sandy bands contain small crystals of magnetite and martite, which give the rock a grey colour. The crystals are usually perfect octahedra, up to about a millimetre across.

Sandstone beds near Tirilposi.

The sandstone beds become more marked near Tirilposi (22° 09′ : 85° 06′) and the Gangpur State boundary, and often become conglomeratic in character. The conglomerate bands, however, do not seem to be very persistent, and can seldom be traced over a very large area.

The beds have the usual general strike varying from N. E.–S. W. to E. N. E.–W. S. W., and a general dip in a north-westerly direction at about 70°; but local folding is fairly common. The sandstone contains a fair amount of chloritic material, which gives the rock a somewhat schistose appearance, especially when weathered. Bands of shale and phyllite occur, but they are small compared with the amount of sandy rock.

The conglomerate bands, which are well exposed in the Bitkulsia (Simlung) *nadi*, south of Tirilposi, consist of well-rounded pebbles usually about one to three inches across, but occasionally as much as eight inches; they are mainly of fine-grained, hard, compact, white or greyish quartzite, cemented together by a sandy or shaly matrix. Some of the shale bands are also very conglomeratic, but the pebbles seem to be less rounded, and consist mainly of pale grey quartzite, with a few of banded hematite-quartzite and an occasional pebble of red jasper.

Current-bedding and ripple-marking are occasionally seen in the sandstone, and are well exposed in the Bitkulsia stream south of Tirilposi.

Thin bands of igneous rock also occur in parts of these sandy beds, and run parallel to the strike and dip of the rocks; but they can be traced only for short distances.

Weathering of the shales.

Most of the varieties of the shale on weathering take on a ferruginous appearance, become red in colour; they may become altered to a laterite. Where the quartzite or sandy bands occur in the shale, or where silicification has taken place, these often form the tops of hills or ridges, and may give an impression of being more important than they really are.

Near the Gangpur boundary in the north-west of the area under description, the shale country is cut up into a series of narrow,

irregular, steep-sided valleys, which make progress across country slow and tedious.

Where the sandstone bands are abundant, as near Tirilposi, they give rise to a very sandy type of soil, and consequently vegetation in these areas is very poor. Streams in these areas are dry for most of the year, as rainwater soon disappears into the sandy soil.

The Breccia-Conglomerate.

The breccia-conglomerate forms a marked band running in a north-east to south-west direction just to the west of the village of Tholkabad, where it is seen to be overlain and underlain conformably by the shales, which often have a red-purple colour. The band is well exposed, and is of considerable thickness, in the hills Marang Buru and Lagirda Buru to the west of Tholkabad, and also in Apasal Buru about three miles south-west of the village. To the south-west of Apasal Buru, the band gets thinner and more phyllitic in character.

The rock has the same general strike and dip as the shales with which it occurs, the latter averaging about 65° to the N. N. W. The pebbles in the conglomerate are mainly of white and pinkish quartzite, banded hematite-quartzite, red jasper, hard cherty shale, and a few of white quartz. They are usually well-rounded, flattened, and have an elongated appearance; but some are quite angular; they are cemented together by greyish silica, with ferruginous and fine-grained, micaceous or sericitic material.

This conglomerate is often covered with laterite, and this is especially the case near Ratamati (22° 09′ : 85° 09′), and in the adjoining Lagirda valley.

This conglomerate is also well exposed in the hill Khendra Buru, two miles to the north-west of Badgaon (22° 02′ : 85° 02′), in the north of Bonai State, where in parts it has a phyllitic appearance. The low ground near the village is composed of granitic rock with some thin basic dykes, and a little schistose rock, probably of the Older Dharwars caught up in the granite. Towards Khendra Buru the ground becomes covered, but the hill itself consists of the breccia-conglomerate, dipping 70° to the north-west. To the north-west of the hill, and overlying the conglomerate, is red-purple shale. The pebbles are well-rounded and usually have a flattened and elongated appearance and consist of hard light.

coloured quartzite, banded hematite-quartzite, shale, red jasper and a few of white quartz. The groundmass of the rock is sandy at times, but more often it is sericitic in character. Pebbles are sometimes scarce and then the rock resembles a phyllite.

In the flatter ground to the north-east of Badgaon, between Khendra Buru and Relhatu (22° 05′ : 85° 04′), the rock has a peculiar mode of occurrence. It occurs as a series of thin slabs, say twenty feet or more long and a few feet wide, standing nearly vertically above the soil-covered ground. These slabs continue at intervals along a track about half a mile wide, and for about two miles along the Relhatu-Jharbera cart-track. The dip of the rock, which is indicated by the slope of these slabs, is actually at about 80° in a north-westerly direction.

To the west of this conglomerate band, the red-purple shales become more and more sandy in character, and in the area to the south of, and near, Tirilposi, the rock is practically a sandstone with a shaly or schistose character, as described on page 204.

CHAPTER X.

THE IRON-ORE SERIES—*concld.*

The Epidiorites and Ash Beds.

To the west of the main iron-ore range is a big outcrop of basic igneous rock, associated with ash beds. These appear to be interbedded with the shales of the Iron-ore series.

Appearance in the field.

When not very much altered the rock is usually of a greenish-grey colour, which varies considerably in texture. It is usually fine-grained with a smooth fracture, but is sometimes rather coarse and highly crystalline with a rough surface fracture. At times it is rather schistose in character, and at other times it resembles a shale.

Alteration in the field.

The rock on weathering often takes on a brownish buff colour. In some cases the weathering and alteration has gone so far that the original minerals of the rock seem to be completely decomposed, and the rock takes on a buff or reddish purple shale-like appearance. When the original rock, however, was amygdaloidal, the amygdales often remain, and then the original igneous character can be recognised. When, however, these amygdales are absent, the rock in the field is often mistaken for the ordinary buff or red shale of the area.

The rocks may be generally termed epidiorites, and although they are very altered, the alteration often is metasomatic rather than dynamic, so that many of the rocks still retain some of their original structures. The rocks appear to have originally been dolerites or basalts, associated with volcanic ashes or tuffs.

Silicification is a very common and widespread type of alteration of these basic rocks, and at times the rock consists almost solely of granular silica, but the silicified rock retains its blue-grey colour. The silicified rock often has thin white veins of quartz running through it.

Another type of alteration is to a quartz-epidote-rock or epidosite. A rock of this type occurs near the Tholkabad-Naogaon road, and is moderately fine-grained, hard and compact, with large irregular patches of quartz and epidote in it. The rock is found

to consist of minute lath-shaped felspar, which occasionally is big enough to show lamellar twinning, in a brownish fuzzy chloritic groundmass full of opaque white granules which appear to be leucoxene. Scattered through the whole is granular epidote, and large irregularly shaped patches of quartz full of granular epidote and some minute needles of the same mineral.

In the hillocks between Garahatu Lor and Lasara Gara (22° 05′ : 85° 15′) is ferruginous material which at first looks like shale, but which on close examination is found to contain amygdale-like patches, which are now filled with granular quartz.

One of these rocks, in which alteration has proceeded so far. that none of the original structure of the rock remains, except the amygdales, occurs in the Tonta Gara (22° 10′ : 85° 19′). It is a reddish purple shale-like rock, containing numerous white amygdales. Under the microscope the rock has a shale-like structure, but seems to be much silicified, and consists of fine quartz or chert full of hematite powder. The amygdales are of quartz with a little chlorite.

Petrological character of the epidiorite.

The minerals originally present in the rock appear to have been augite and lath-shaped felspar arranged in ophitic manner, and ilmenite. The minerals are usually very altered, and in some cases none of the original minerals remain, and the original ophitic structure of the rock may have disappeared. The felspar is usually more or less altered to saussurite, and in some cases is completely replaced by chlorite, kaolin, quartz, calcite, etc., but these alteration products, often retain to some extent the shape of the original lath-shaped felspar. The augite is usually of later crystallisation than the felspar, and parts of one augite individual are often broken into detached areas by the felspars. The augite is usually altered to hornblende and chloritic material. The ilmenite may be completely altered to leucoxene and sphene.

Porphyritic epidiorite.

A porphyritic type of rock occurs in the Tonta Gara (22° 10′ : 85° 19′) which is dark grey in colour, coarse-grained and has some small phenocrysts of felspar (Plate 22, fig. 1). The rock is found to consist of lath-shaped felspar, somewhat kaolinised and containing micaceous alteration products; nearly colourless augite, very altered, enclosing and broken up into isolated patches by felspar laths. The alteration of the augite is to hornblende and chlorite. Ilmenite is present in

fair quantity, but is largely altered to leucoxene. There appears to be some secondary quartz.

Koraj *nadi*.

These basic igneous rocks are well exposed in the Koraj *nadi* between Korai (22° 02′ : 85° 12′) and Gunjaghara (22° 01′ : 85° 13′), where they are seen to be massive, fine-grained, very siliceous and occasionally amygdaloidal. The rock is sometimes cut up by small quartz veins, which run in all directions. It is found to consist of lath-shaped felspar completely replaced by silica, and fuzzy indeterminate material with occasional patches of chlorite. Some bleached ferromagnesian mineral (? augite), completely altered, is present. A few amygdaloidal patches occur, and they are made up of quartz with fuzzy indeterminate material, in which are scattered fine granules of epidote.

Jambai.

The rock near Jambai (22° 07′ : 85° 13′) is fine grained, bluish grey and hard, which becomes buff-coloured on the weathered surface. The rock when examined with the microscope is found to be made up of very altered laths of felspar, with fuzzy indeterminate material between them. Some amygdaloidal patches are filled with quartz, a little magnetite and chlorite, and some granular epidote.

Naogaon.

On the main road, just to the north of Naogaon (22° 08′ : 85° 14′), is a good exposure of basic igneous rock of a coarse-grained, dark grey variety. The rock is fairly fresh and when examined under the microscope, is found to resemble the Newer Dolerites rather than the interbedded epidiorites, and is possibly a dyke which has cut through the interbedded rocks. The rock consists of stout crystals of felspar, partly kaolinised and showing little lamellar twinning, large platy crystals of nearly colourless augite, altered in places on the edges of the crystals to brownish hornblende and greenish chlorite. Some of the augite crystals show simple twinning. A small amount of ilmenite occurs partly altered to leucoxene.

Churdia Lor area.

In the low ground north-west of the Sasangda ridge basic igneous rock occurs, with which are associated ash beds. The rocks are well exposed in the lower slopes of the ridge, and in the streams running into the Churdia Lor (22° 09′ : 85° 17′). In the field these rocks often have a very shale-like appearance, striking north-east to south-west, and dipping at 80° to the north-west. Both the basic rock and the

ash have a greenish grey colour, and are medium-grained. When examined with the microscope, the ash is found to be made up of angular and rounded fragments of white kaolinised material and quartz, with an occasional fragment of some ferromagnesian mineral partly altered to chlorite. Some fragments of what appears to have been a vesicular rock also occur. Some of the fragments appear to be a devitrified glass, which occasionally show spherulitic structure. There are also some fragments of epidiorite-like rock. The fragments are set in a fine-grained groundmass, which consists mainly of chloritic material and quartz, with some micaceous alteration products.

The basic rock associated with these ash beds is fairly fresh, and under the microscope is found to consist of stout idiomorphic crystals of augite, nearly colourless in the centre, but often having a pale brownish colour at the edges. The crystals are often twinned, and in some cases show frayed ends, where alteration has begun to take place. The felspar has a tendency to idiomorphism, but is usually very altered and the outline is often somewhat obscured. The alteration products appear to be finely divided calcite, kaolin, chlorite and micaceous products. A little interstitial quartz is present, and ilmenite occurs almost completely altered to leucoxene.

Duargui *nadi* area.

A somewhat similar patch of basic rock with ash beds is exposed in the Duargui *nadi* (22° 11′ : 85° 20′) and is possibly a continuation of those noted above occurring in the low ground west of the Sasangda ridge. The basic rock is medium-grained, and of a pale greenish grey colour. It sometimes contains large pale greenish-white phenocrysts, which are usually rectangular in section, and vary up to one inch in length. Originally these phenocrysts were undoubtedly felspar, but have been completely altered into kaolin, quartz, chlorite and micaceous products. The main mass of the rock is made up of almost colourless augite, penetrated by altered felspar laths. A little ilmenite largely altered to leucoxene and sphene occurs, and there is a little chlorite and pyrite present.

Dadan Raikela.

An interesting exposure occurs in the Kurhadi *nadi*, near Dadan Raikela (21° 53′ : 85° 06′). Here there is a bed of pale greenish-grey volcanic ash or fine-grained tuff, in which a number of well-rounded and occasionally angular boulders up to a foot or more in diameter, of fine-grained epidiorite occur. It seems probable that these were volcanic

bombs, which on settling on the surface were covered with other volcanic debris. These rounded boulders are well shown in Plate 21, figs. 1 and 2. The volcanic ash is a fine-grained, greenish grey, somewhat schistose-looking rock, in which some irregular fragments are seen. The microscope shows the rock to be made up of fine fragmental material. The rock forming the rounded boulders is a rather hard, fine-grained, compact rock, and has quite a different appearance from the ash in which it occurs. It sometimes contains areas of white quartz, which were probably steam-holes when the rock was in a molten condition. The rock is a fine-grained epidiorite.

CHAPTER XI.

THE GRANITIC ROCKS.

Introduction.

In the area under description there are two main masses of granite: the Singhbhum granite and the Bonai granite. The Bamra granite mass to the south-west of the area under description has been slightly more metamorphosed than the others and this gives it a somewhat gneissic character. It is thought that these granites come from the same magma and were all intruded at about the same time. The rocks are very similar in mineral composition, and are all intrusive into and therefore are certainly of later age than, the Iron-ore series; they are older than the Newer dolerites which occur as dykes in them.

I stated in 1922[1] that the Singhbhum granite was intruded into the Dharwars, and into the Iron-ore series. Dr. Fermor[2] in 1908 stated that the gneissose granite of Singhbhum is possibly intrusive into the Dharwars; and in the same year he found conclusive evidence that the granite of Central Singhbhum was intrusive into the Dharwars, as also in 1918 of the intrusive relations of the granitic rocks of the chromite area of Jojohatu to the Dharwars and the peridotites[3]. Also Dr. Dunn[4] states that the Singhbhum granites show an intrusive relation to the Iron-ore series, and that the Singhbhum granite is one of the final representatives of the Archæan system, and that the Newer Dolerites, which occur as dykes in the granite, are possibly of Cuddapah age.

The Singhbhum Granite.

In the area worked by me, the Singhbhum granite occurs over a large area in the plain to the south and south-east of Chaibassa.

Relation to other rocks. It is a huge boss intrusive into the Older Dharwars and the Iron-ore series, which seems to have had very little metamorphic effect on the rock into which

[1] H. C. Jones, 'The Iron-ores of Singhbhum and Orissa', *Rec. Geol. Surv. Ind.*, LIV, p. 207, (1922).
[2] General Report for 1908, *Rec. Geol. Surv. Ind.*, XXXVIII, p. 18, (1909).
[3] *Rec. Geol. Surv. Ind.*, L, p. 22, (1919).
[4] J. A. Dunn, *Mem. Geol. Surv. Ind.*, LIV, p. 99, (1929).

it was intruded. This granitic intrusion raised rather than broke up the rocks of the Iron-ore series, but a certain amount of absorption and penetration can be seen at Simjang (22° 26′ : 85° 45′) and other places. The purple sandstone, the limestone, and the lower shale of the Iron-ore series are all found in contact with the granite at different places, which seems to indicate that the lower beds in some parts have been largely absorbed. The rocks of the Iron-ore series have a general dip away from the granitic mass, and possibly some of the folding and faulting noted, is due to this intrusion.

Quartz veins and veins of pegmatite frequently occur in the granite mass. There are two main systems of jointing in the granite which strike about N. 35° W. to S. 35° E. and N. 55° E. to S. 55° W. The dolerite has been largely intruded along these joints, giving rise to the basic dykes which are such a feature of this granite area.

Weathering.

The granite is a fairly soft and easily weathered rock, and therefore makes no very marked surface features. It usually has a fairly thick covering of weathered, partly decomposed rock and soil, which forms the large cultivated plains in the south-east of the Singhbhum district. Tors and typical granite scenery are only occasionally met with in the area, and the granite country is generally flat.

Texture and composition.

The rock varies from very fine-grained to a coarse porphyritic type, and in places it has a slightly gneissic character. The rock is usually pale grey or white in colour, fairly acid in composition and contains a large proportion of plagioclase felspar. The rock usually consists of quartz in small amount, plagioclase felspar (oligoclase-andesine), orthoclase, microcline, hornblende and rare mica (muscovite and biotite). Accessory minerals are usually apatite, zircon, epidote, and ilmenite, which is usually partly altered to leucoxene. The ferro magnesian minerals, which are usually in small quantity are often altered to chlorite, with the separation of fine grains of magnetite. This sometimes gives the rock a greenish tinge.

On the west, near where it is seen in contact with the Iron-ore series, it is decidedly more acid in character than farther away; this is possibly due to absorption of siliceous material from the Lower Dharwars and the Iron-ore series. In places it seems to have converted some of the sandstones into quartzites.

The rock when examined under the microscope is found to have undergone a considerable amount of strain and crushing, which is shown by the strain shadows in the quartz and felspar crystals, the breaking up of the quartz grains, and the bending and fracturing of the twin lamellæ in the felspar. The felspars easily alter to kaolin and sericite.

Petrological descriptions.

The rock near Singabera (22° 11′ : 85° 39′) has a slightly gneissic character. Specimens shows it to consist of dark grey granitic bands alternating with bands of nearly white granitic material. The microscope shows the nearly white variety to consist of much altered felspar, quartz in small quantity, sometimes containing small fluid inclusions, green hornblende, much epidote in bands, with some accessory apatite and sphene, and a little chlorite. The darker part is much more granitic in texture, and consists largely of plagioclase and green hornblende. Some quartz and a little orthoclase is present. Both the plagioclase and the orthoclase are much altered. Apatite, epidote and zircon are present as accessories, and some ilmenite altering to leucoxene. Some of the hornblende is altered to chlorite. Close to the granite–Iron-ore series boundary, the rock has a decidedly acid character, which is possibly due to the absorption of quantities of the siliceous material of the Lower Dharwars and the Iron-ore series. A specimen collected from Simjang (22° 26′ : 85° 45′) is a medium-grained granitic rock, which when examined under the microscope appears to be a typical granite, consisting of quartz and orthoclase felspar in large quantity, with some muscovite. The orthoclase is very much kaolinised. A certain amount of microcline and plagioclase is present, and these seem much less altered than the orthoclase. The muscovite is partly altered to chlorite. Apatite and ilmenite are present as accessories, the latter being partly altered to leucoxene. Another specimen from the small exposure near Bandijari (22° 26′ : 85° 41′) is a medium-grained, pale grey granite, which under the microscope is very similar in general character to the one noted above as occurring at Simjang; but the rock seems to have undergone a considerable amount of strain, and crushing. Some veins of secondary quartz occur running through the felspar crystals.

Some of this granite rock would give an excellent building stone, and it has been largely used in the building of bridges, etc., for the new Amda-Jamda railway.

Lit-par-lit injection of the granitic rock into the Older Dharwar rocks is well seen in the Deo river, near Mungra, where the granitic rock has penetrated and broken up the Older Dharwar schists and quartzites into small patches (Plate 14).

Lit-par-lit injection near Mungra.

Kaolin or China clay is being worked at several points near Dumria and Karanjia (22° 12′ : 85° 44′). The clay has resulted from the kaolinisation and alteration, probably by hydrothermal agencies of the granite. The material is rather impure, but is being washed, made into bricks and dried before despatch to Calcutta for paper-making.

Kaolin.

The Bonai Granite.

This granitic rock has already been noted as being similar in character to the Singhbhum mass. Similarly it seems to have had very little metamorphic effect on the surrounding rocks into which it has been intruded. It is a soft and easily denuded rock and therefore makes no marked surface features. It forms gently undulating country which is broken up by small knolls and low hillocks. The granitic country is often cultivated.

The rock is medium-grained, and consists largely of plagioclase felspar (oligoclase), with a fair amount of quartz. Microcline is usually abundant and there is a certain amount of orthoclase. Muscovite is usually present in small quantity, and accessory minerals are not abundant. It often has a gneissic character, and when examined under the microscope it appears to have undergone a great deal of strain.

Texture and composition.

The granite near Jamdih (21° 59′ : 85 07′) is a pale grey medium-grained rock, which under the microscope is seen to have suffered much strain. It shows plagioclase felspar with very bent and fractured twin lamellæ, strain shadows, and fractures which have been filled with secondary quartz. The original quartz shows strain shadows, and is somewhat granulated. The felspar includes orthoclase and microcline. There is a little muscovite and fine-grained micaceous substance present.

Petrological descriptions.

Near Balijod (22° 03′ : 85° 08′) the rock is pegmatitic and the felspar has been largely altered to kaolin. Although this clayey material occurs in small patches over a fairly large area, the kaolinisation does not appear to have gone far enough to make the occurr-

ence of special economic value ; but it is a source of attraction for sambhar and other animals of the district. Pale blue-grey and white quartz are marked in this area, and possibly provided some of the material for the Cuddapah sandstones.

Hybrid Rock.

Near Chalpagara (22° 21′ : 85° 37′) there is a peculiar hybrid rock in the Iron-ore series, very intimately connected with a dolerite dyke. The rock, which has a reddish tinge, varies considerably from a hard fine- to medium-grained rock of granitic aspect, to a purplish schistose type. The former under the microscope shows a myrmekitic intergrowth of quartz and felspar. The felspar is filled with powdery red hematite. Some chlorite and magnetite and some small quartz veins are present. The schistose variety shows a similar myrmekitic character, but the chlorite is represented by fine sericitic material and the magnetite is almost completely altered to hematite. In places the dolerite seems to have irregularly penetrated and absorbed some of this rock, and the result is a dark green, rather granular rock, which under the microscope shows the same myrmekitic intergrowth of quartz and felspar ; but there is a much larger proportion of chlorite present.

CHAPTER XII.

THE ULTRABASIC IGNEOUS ROCKS.

Ultrabasic igneous rocks occur as small isolated patches throughout the area. The most important is that occurring near Jojohatu, about ten miles W. S. W. of Chaibassa, and in which the Singhbhum chromite deposits occur. Dr. Fermor[1] described these in 1918 and says :—

'The ultrabasic rocks appear to be laccolitic intrusions several hundred feet thick that have participated in the later stages of folding of the Dharwars'.

He considers the ultrabasic rock to be intrusive into the Iron-ore series, and of earlier age than the granite.

Dr. Dunn[2] in referring to the ultrabasic rocks of North Singhbhum says :—

'It might be safely assumed that the intrusion of the ultrabasic rocks was not only later than the metamorphism of the Iron Ore series but also later than the severe movement of the shear zone.'

He also says :—

'The ultrabasic igneous rocks are intruded into the Iron Ore series and as the granite in its turn is intruded into them they are definitely post-Iron Ore series and pre-granite.'

In my examination of several patches of ultrabasic rock in South Singhbhum and Bonai State, there is no doubt that these are intrusive into the Iron-ore series. I have not found a case, however, where the ultrabasic rock has been intruded by the granite. In the Bonai State there are several dyke-like masses of ultrabasic rock which occur in the granitic rocks, and appear to be post-granite.[3] The rocks are very altered, but show little sign of the disturbance to be seen in similar rocks near Jojohatu.

Near Rangra (22° 03′ : 85° 09′) in Bonai State, one of these dyke-like patches of ultrabasic rock is cut across by one of the Newer Dolerite dykes, thus proving the ultrabasic rocks to be pre-Newer-Dolerite in age.

These patches vary in length up to about three miles, and as usual the area covered by these rocks is marked by the absence,

[1] General Report for 1918, *Rec. Geol. Surv. Ind.*, L, p. 10, (1919).
[2] *Mem. Geol. Surv. Ind.*, LIV, p. 96, (1929).
[3] *See* footnote on page 178.

or by the stunted growth of the *sal* trees. The rock is usually coarse-grained, tough and very black in colour; but, when very weathered the rock becomes almost completely altered to serpentine, when it has a pale green somewhat earthy appearance. The rock is very similar in the different patches, and they probably all came from the same source.

Tonto.

The Tonto intrusion occurs north of the village of Tonto (22° 23′ : 85° 37′) and at the foot of a small hill formed by a sandy band in the shales. The material collected from here is a medium-grained, greenish black rock, which when weathered, seems to be made up of plates of bastite which show a schiller character, and have probably resulted from the alteration of hypersthene. In places the rock is serpentinised. When examined under the microscope, the freshest rock obtained is seen to be almost completely altered to serpentine and sericitic material. The serpentine has evidently resulted from the alteration of olivine as mesh structure is often observed, but no unaltered olivine remains. A little colourless augite is present, occurring as residual grains in an almost completely altered crystal. Some small black opaque crystals are seen in the slide, and these may be magnetite or chromite. The rock is cut up by veins of tremolite and asbestos (chrysotile), some of which have been altered to talc.

Nurda.

The intrusive rock at Nurda (22° 20′ : 85° 44′) is also very much altered, and it is very difficult to find anything approaching a fresh specimen. The mass is very cut up by veins and bands of pale yellow serpentine and by thin veins of fibrous asbestos. The veins of asbestos are thin and of no economic value. The whole of the rock seems to be serpentinised. Some of the Nurda rock is extremely fine-grained and has a pale green colour, which under the microscope appears to be a glass, in parts altered to serpentine.

Badgaon.

The patch of ultrabasic rock to the south of Badgaon (22° 02′ : 85° 02′) is very much altered and seems to be much intermixed with an impure steatitic schistose rock which has probably resulted from the alteration of the ultrabasic rock. The patch thins out in the hills south-west of the village, but the ground here is covered. The rock is of a green colour and appears to be very altered. It consists almost entirely of serpentine material.

Rangra.

Near Rangra (22° 03′ : 85° 09′) the rock contains thin veins of asbestos, but there does not seem enough of this to be of real economic value, although in the fields to the north-east of the village, the soil contains quite an appreciable amount of asbestos fragments. At the east, and near the top of the hill to the north of Rangra village, a silicified basic dyke striking N. N. E. to S. S. W. is seen cutting across the ultrabasic rock; but it has no marked metamorphic effect. The ultrabasic rock when examined under the microscope is found to be largely serpentinised, but the original rock seems to have been a peridotite, and consisted mainly of colourless augite and olivine. Scattered through the rock are small black opaque grains which appear to be magnetite. A very little chlorite is also present as an alteration product.

The dyke-like patch of ultrabasic rock south of Nangalkata (22° 05′ : 85° 05′) extends for about four miles. It is fine-grained and shows the usual pitted, greyish brown, weathered surface. The rock consists mainly of serpentine with a few plates of augite almost completely altered to serpentine. Scattered throughout the rock is some black powdery material which is probably magnetite.

CHAPTER XIII.

THE NEWER DOLERITES.

In the section dealing with the geological history of this area, I have said that the intrusion of the granite was followed by earth movements, and that basic igneous rock was forced up along joints and cracks in the granite which gave an easy passage to the molten magma. This gave rise to the very extensive series of dykes which are such a marked feature of the Singhbhum granitic area to the south of Chaibassa, and also in the Bonai granite mass. These dykes have a general N. N. E. to S. S. W. strike, but there is a minor series having a N. N. W. to S. S. E. strike. In Keonjhar State, they generally run N. 30° E., which corresponds to one set of joints in the granite. Occasional dykes run in any direction, and evidently occupy irregular cracks in the rock.

The rocks are dolerites and basalts and have been termed the Newer Dolerites.[1]

This basic igneous rock has also penetrated the Iron-ore series to a small extent, where it occurs both in the form of dykes and sills. The dykes in the Iron-ore series are usually small, and can only be traced for short distances.

The dykes in the Bonai granite are similar to, and seem to be almost as numerous as in the Singhbhum granite. They also occur, but are not nearly so abundant in the Bamra granite-gneiss as in the granites noted above.

In one case near Rangra (22° 03′ : 85° 09′), one of these dykes is seen cutting through a mass of ultrabasic rock, showing that these rocks are of later age than the ultrabasic intrusion.

In the granite area these dykes are a very marked feature, and occur as long, often straight ridges up to half a mile in width, and often running for many miles across country. The ridges are sometimes discontinuous, and are usually covered with roughly spheroidal boulders. The lower slopes of the ridge usually has a dark reddish soil, which supports a thin scrubby vegetation.

[1] General Report for 1925, *Rec. Geol. Surv. Ind.*, LIX, p. 66, (1926).

The rocks vary considerably in texture, some being extremely fine-grained, and others very coarse-grained; sometimes they are amygdaloidal. These variations are doubtless mainly due to the width of the dyke, which influenced the rate of cooling. The rock is at times fairly fresh and unaltered, and this seems to be especially the case when the dyke occurs in granite. The rock varies from a fine-grained basalt to a coarse-grained dolerite, and is usually of dark bluish or greenish grey colour, due in great part to the presence of secondary chlorite, and the microscopic examination shows the rock to be of very similar composition over wide areas. The rock is made up of lath-shaped plagioclase felspar (labradorite to bytownite) and pale brownish to colourless augite, often in ophitic intergrowth. The felspar in these rocks generally seems to have preceded the augite in order of crystallisation. Quartz sometimes occurs as an original constituent, and is found in micro-pegmatitic intergrowth with the felspar. Generally the felspar is largely altered to saussurite and kaolin, and the augite to hornblende and chlorite with the separation of fine magnetite grains. Ilmenite is abundant, partly altered to leucoxene and sphene, and pyrite sometimes occurs. Secondary epidote, and secondary quartz are also sometimes seen. The felspar in the rock is sometimes replaced by quartz, but the original idiomorphic outlines of the felspar has often been retained. The ferro-magnesian minerals have usually been somewhat chloritised. Porphyritic structure sometimes occurs, when large stout crystals of more or less altered and irregularly green tinged felspar occur in a fine-grained grey rock. The acid character of some of these rocks may be due to the composition of the original magma or to absorption of the granite or other rock that the molten magma passed through. This excess of silica has separated out as quartz, and has formed a micro-pegmatitic intergrowth with the felspar.

Petrology.

The dolerite dykes resist weathering better than the granite, and consequently are often left standing as narrow, low, serrated ridges, which can often be traced for many miles. At times they rise a few hundred feet above the surrounding granitic plain. They often show columnar structure and typical spheroidal weathering, which gives rise to a mass of rounded boulders on the slopes and edges of the dolerite ridge. Sometimes, owing to earth movements, the rock has been crushed and the weathered spheroids have a

Weathering and alteration.

flattened and distorted appearance. The rock breaks down into a greenish grey to reddish brown soil, which supports a scrubby vegetation.

At times these basic rocks, especially when they occur in the form of sills, show a tendency to alter to a lateritic material, and they are often covered by a layer of laterite. The weathering of these rocks is at times very similar to the Iron-ore shales.

The sills appear to be usually more altered than the dykes, which is possibly due to circulating waters finding it easier to traverse a sill than a dyke.

Silicification of these rocks is often very pronounced, and at times the rock consists almost solely of granular silica with a little chloritic or micaceous material.

Chloritisation is another type of alteration that occurs, and a dyke that occurs near Chalpagara (22° 21′ : 85° 37′) is found to be almost completely replaced by chlorite. A certain amount of secondary quartz occurs, and the rock is largely cut up by thin white quartz veins.

Lokesai.

The sill of basic rock south of Lokesai (22° 13′ : 85° 35′) is a typical dolerite; but in places it has weathered to a brown sandy or shaly-looking rock, and where the original rock has been amygdaloidal, the altered rock still contains the amygdales and there is no doubt of its origin; but when there are no amygdales in the original rock, the altered rock might easily be mapped as a sandy shale. In these hills, also, some of the trap seems to have been largely silicified, and is now represented by cherty rocks. Some of the rock in this sill has been largely altered to lateritic material.

Kundiasai.

At Kundiasai (22° 15′ : 85° 40′) is a fairly large dolerite dyke with some thin veins of epidote, running through the granite. At the centre of the dyke, the rock is very coarse-grained, but on the edges where the rock has cooled quickly, it is extremely fine-grained. The microscope shows augite partly altered to chlorite, much altered plagioclase, ilmenite partly altered to leucoxene, and some secondary quartz.

Ilagara.

A good exposure is seen at the waterfall (*see* Plate 22, fig. 2), in the Ila Gara, 1½ miles east of Ilagara village (22° 20′ : 85° 46′). Here the beds of the Iron-ore series are bent into a flat syncline pitching south-west, and the dolerite, which occurs as a sill, is seen to be overlain by sandstone

and then by shales, and overlies sandstone with thin bands of shale, which accounts for the waterfall at this place. The lower sandstone is partly converted into a quartzite. Dr. Dunn[1] states that to the north, this sill continues as a dyke in the granite. It appears, therefore, that the dolerite came through cracks or joints in the granite and occurs as a dyke, but on reaching the Iron-ore series, it seems to have penetrated the bedding planes and taken the form of a sill.

Horomutu.

The large mass of basic rock east of Horomutu (22° 03′ : 85° 18′), is very largely weathered to a soft shaly-looking rock of a purple or buff colour, and resembles the ordinary shales of the area. The resemblance is so marked that it is very difficult to distinguish between the two when mapping. Occasional small amygdales can be seen in some of the bands, and then there is no doubt. At times, as in the exposures in the Roger *nala*, the rock is fairly fresh, dark grey dolerite, but near the Karo river it passes into reddish shale-like material.

Sill south-east of Kotgarh.

To the south-east of Kotgarh (22° 13′ : 85° 32′) is a hugh sill of basic rock, which has been intruded between purple sandstones and an underlying shale. The sill is exposed over an area of about sixteen miles in length by about four to six miles wide. On the east side of the Noamundi mine main ridge, the rock seems to dip into the hill below the shales and the banded hematite-quartzite of the Iron-ore series. To the south-east the rock seems to have been intruded between the Older Dharwars, and the overlying sandstone.

Bonai dolerites.

In the Bonai area the granite rock and the Iron-ore series are similarly intruded by basic igneous rocks, which occur mainly as dykes, but occasionally as sills. These dykes, which usually occur as low serrated ridges in the granite, are very numerous; and, although they run in all directions, the majority seem to strike E. N. E. to W. S. W. They also occur as dykes and sills in the Iron-ore series, but are not nearly as numerous as in the granite. In some cases, as west of Badgaon (22° 02′ : 85° 02′), these dykes are very wide, say one quarter of a mile or more. The rock forming the dykes is often fairly fresh, especially when the dyke occurs in the granite, and

[1] Manuscript report, *Geol. Surv. Ind.*, (1922).

varies from a very fine-grained basalt to a quite coarse-grained dolerite. The structure is often markedly ophitic. The rock usually consists of lath-shaped plagioclase felspar (labradorite to bytownite), pale-coloured to colourless augite, and ilmenite. The minerals are sometimes very altered; the felspar being altered to sericite and saussurite, the augite partly or completely altered to hornblende and chlorite, ilmenite altered to leucoxene and sphene. Pyrite is occasionally present. Porphyritic structure is sometimes seen when large stout crystals of more or less altered felspar occur in a fine-grained grey rock. The sills appear to be more altered than the dykes.

Purnapani.

In the hills east of Purnapani (22° 01′ : 85° 06′), there seems to have been a series of dykes running in all directions, the molten rock having penetrated numerous joints and cracks in the granite. The rock forming the hills Mahatra, 2,018 feet, etc., to the east of Purnapani and to the north of Jamdih (21° 59′ : 85° 07′) are fairly coarse dolerites. The rock varies somewhat, depending on the amount of alteration it has undergone. At the top south end of hill 2,018 feet, the rock is bluish grey in colour, fairly coarse-grained and fresh. This under the microscope is found to be a typical dolerite with a coarse ophitic structure, and to consist of stout laths of plagioclase felspar partly saussuritised, large irregular plates of pale brown augite, a little biotite and some magnetite. On further alteration, the felspar becomes completely saussuritised and sericitised, and the augite altered into hornblende and chlorite.

Kunduruburu.

A band of porphyritic basic igneous rock occurs in the Erua *nadi* to the west of Kunduruburu (21° 58′ : 85° 08′). The rock is grey and rather coarse-grained, in which are large phenocrysts of what were once crystals of felspar. The microscope shows the rock to have an ophitic structure, and is found to consist of large crystals of pale-coloured augite, sometimes showing simple twinning. A little micrographic intergrowth of quartz and altered felspar. The augite in places is altered to brownish hornblende. Some ilmenite altering to leucoxene occurs. A little primary and some secondary quartz is present. The felspar is largely replaced by sericitic material. The large phenocrysts of felspar are represented by saussuritic and sericitic material.

PART II.—THE IRON-ORE.

CHAPTER I.

HISTORY OF IRON IN INDIA.

Ancient History.

It is not known when iron was first introduced or was first produced in India, but it is believed that the art of smelting and working iron was known in Asia, long before it reached Europe. The antiquity of the knowledge of iron-smelting and working in India may be judged from some of the remains which occur in various parts of the country, such as the famous Iron Pillar near the Kutb-Minar near Delhi; this pillar is estimated to be about 1,500 years old, and it is still a mystery how such a large mass of iron was produced. For this pillar is of solid wrought iron and weighs over six tons. India also supplied the material from which the famous Damascus blades were made. The indigenous Indian iron industry until comparatively recently was a very thriving one, spread over a large part of the country, and there is hardly a district away from the great alluvial tracts of the Indus, Ganges, and Brahmaputra, in which slag-heaps are not found. But it has almost died out as it could not compete with either the imported metal, or metal produced on a large scale in India, and the supply of charcoal for smelting purposes was diminishing and being controlled. Iron-ores in large enough quantity and of sufficiently high grade to meet the demands of the local smelter, occur in almost all districts of India except in the alluvial plains of the big rivers, but very few of these sources of supply would be of any use to the modern iron-smelter. The local smelter used the richer fragments which had weathered out of laterite, the rusty material weathered out of sandstones, parts of the quartz-magnetite- or quartz-hematite-rock which occur in various parts of India, but the iron-ore and the quartz in these last two types are so intimately mixed, that only a low grade highly siliceous ore is usually obtained. Magnetite sands were also sometimes used.

The only province for which statistical data are collected relative to the indigenous iron industry is the Central Provinces. But

there also the industry is steadily declining, as shown by a fall in the number of furnaces at work from 229 in 1924 to 196 in 1928 and 106 in 1931.[1]

The industry still survives also in some of the isolated parts of Bihar and Orissa, and when I was in Bamra State in 1925, there was quite a colony of iron-smelters at work with their primitive blast-furnaces about three to four feet in height.

Early European Methods.

Mr. Josiah Marshall Heath of the Madras Civil Service appears to have made the earliest attempt to introduce into India European processes for the smelting of iron. He obtained from the East India Company the exclusive right of manufacturing iron on a large scale in the Madras Presidency. He resigned the service, and in 1830 started works at Porto Novo, on the Madras coast in the South Arcot district, but had exhausted his funds at the end of a year. He was helped at times by the East India Company, but little was done until 1833 when he formed a company called the Porto Novo Steel and Iron Co. Within three years this company was in difficulties and the undertaking eventually proved to be a failure. Attempts were made in 1847 and again in 1850 to form a new company, but it was not until 1853 that the East India Iron Company, was formed with a capital of £400,000. This company obtained various concessions from Government, and erected a blast-furnace in the South Arcot district and another on the Cauvery river, in the Coimbatore district. The smelting was done by means of charcoal and the Directors of the company soon saw that the obtaining of sufficient supplies of it was going to be a difficulty, so work was stopped in 1867 and the Company was dissolved in 1874.

Attempts to manufacture iron on a large scale in Bengal appear to have started in 1777 by Messrs. Motte and Farquahar, who were granted the exclusive privilege of manufacturing iron to the west of Burdwan. Mr. Farquahar obtained an advance from Government in 1779, but ten years later he gave up the experiment.

Several attempts were made to smelt the iron-ores of the Birbhum district between the years of 1855 to 1875, but they were all abandoned. Other attempts to introduce European methods in other parts of the country, such as at Kaladhingi in Kumaon, and

[1] *See* the Quinquennial and Annual Reviews of Mineral Production in India in the *Rec. Geol. Surv. Ind.*

in Sirmur State all ended in failure. In all these experiments, charcoal was the fuel used.

In 1874 the Barakar Iron Works Company was formed and was the first company to use coke as a fuel. Two blast-furnaces were erected at Kulti near Barakar, each capable of producing 20 tons of pig-iron a day. The ore used was clay-ironstone obtained from near the works. The coke was made from coal obtained within a few miles of the works, and the limestone used as a flux was obtained from the crystalline rocks close by. The company closed down in 1879 owing to monetary difficulties, and the concern was taken over by Government in 1882 and was resold by them in 1889 to the Bengal Iron and Steel Company, with Messrs. Martin and Company as managing agents, who entirely remodelled and gradually developed the concern. In 1905 the Company opened a steel department, but owing to small demand this was soon closed down. In 1919 the company changed its title to 'The Bengal Iron Company, Ltd.'. This was the first scheme that turned out to be a financial success in India, and was the beginning of a modern iron industry on a large scale. The Company in its early days obtained its ore from the Ironstone Shales, supplemented by magnetite collected from near Kalimati, and from other deposits in Manbhum; but in 1907, the late Mr. R. Saubolle, who was prospecting for Messrs. Martin and Company, brought limonite and other minerals to Dr. L. L. Fermor, then curator to the Geological Survey. The iron-ores were from Notu Buru and Budu Buru in the Saranda area of Singhbhum. In view of the high quality of the specimens submitted, Dr. Fermor advised Mr. Saubolle to return at once and apply for prospecting licenses over the hills in question. The Company obtained mining leases over these areas, and commenced despatching iron-ore from Pansira Buru (a portion of Notu Buru) in 1910. This discovery by Mr. Saubolle led to the further rejuvenation of the fortunes of the Bengal Iron and Steel Company, Ltd., and by the impetus it gave to prospecting in Saranda, it led to the discovery of the vast stores of iron-ore that form the subject of this memoir, and thereby rendered possible the ultimate expansion of the Tata Iron and Steel Company referred to below to a scale that would otherwise have been impossible, and also rendered possible the flotation of the Indian Iron and Steel Company.

Mr. Jamsetji Nusservanji Tata appears to have been interested in a 'Report on the financial prospects of iron working in the Chanda

district', by R. von Schwarz, in which was a description of the Lohara iron deposit in the Central Provinces. Mr. Tata went to England and America in 1902 and engaged the services of Mr. C. P. Perrin and his associate, Mr. C. M. Weld, both of New York. In early 1903 Mr. Weld prospected in the Chanda district, and although the iron-ore was all that could be desired, there was no suitable coal anywhere near.

Mr. P. N. Bose discovered iron-ore at Gurumaisini in Mayurbhanj State in 1904, and brought the occurrence to the notice of Mr. Tata. Mr. Perrin and Mr. Weld made investigations and found the deposits were rich and fairly close to the Jharia coalfield. The Tata Iron and Steel Company was formed in 1907, and mining leases were obtained from the Maharaja of Mayurbhanj, the royalty being an average of 2·625 annas per ton for the first thirty years, and 5 annas per ton for the next thirty, on a minimum extraction of 200,000 tons of ore annually.

The site selected for the works was at a small village known as Sakchi (now Jamshedpur), close to the junction of the Subarnareka river and the Khorkai river. The first blast-furnace was blown in November, 1911, and since that time this furnace has been enlarged and reconstructed and four other blast-furnaces have been erected.

The rich deposits taken up by the Bengal Iron and Steel Company, Ltd., led to further prospecting, which led to the discovery of large deposits of iron-ore in Singhbhum, and in the Feudatory States of Keonjhar and Bonai.

In his Memoir on the geology of the districts of Manbhum and Singhbhum, V. Ball[1] gives a general account of the distribution of iron-ores in these two districts; but the portion of Singhbhum mapped by Ball, and consequently the localities mentioned by him, lies to the north of the areas examined by me. Failure to provide for the continuance of systematic mapping to the southwards led to the discovery of the rich iron-ores of Saranda being postponed for thirty years.

Dr. J. M. Maclaren[2] examined the auriferous occurrences of Chota Nagpur, and in his account he describes the geology of the area, but makes no mention of the iron-ore.

[1] *Mem. Geol. Surv. Ind.*, XVIII, (1881).
[2] *Rec. Geol. Surv. Ind.*, XXXI, (1904).

Dr. Fermor[1] in his account of the manganese-ore deposits refers to the iron-ores of Singhbhum, but this deals mainly with the area near Chaibassa.

Sir Thomas Holland and Dr. Fermor[2] in their Quinquennial Review of Mineral Production for 1904 to 1908, mention the discoveries of iron-ore at Notu Buru and Buda Buru in Saranda, respectively 12 miles E. S. E. and eight miles south-east of Manharpur Station, Bengal-Nagpur Railway. In 1918 Dr. Fermor visited Pansira Buru (a portion of Notu Buru) and gave an account thereof.[3]

In the Quinquennial Review[4] of the Mineral Production of India for 1909 to 1913, it is stated, referring to the Bengal Iron and Steel Company, Limited, that 'recently magnetite and hematite have been obtained from the Manbhum and Singhbhum districts'. In this Review it is also stated that finally this company have now given up the use of ores obtained from the neighbourhood of Barakar and Raniganj, and are now obtaining their ores exclusively from Pansira Hill and Buda Hill in the Kolhan Estate, Singhbhum.

[1] *Mem. Geol. Surv. Ind.*, XXXVII, (1909).
[2] *Rec Geol. Surv. Ind.*, XXXIX, p. 105, (1910).
[3] *Op cit.*, L, p. 14, (1919).
[4] *Op. cit*, XLVI, p 105, (1915).

CHAPTER II.

THE ORE-BODIES.

Mineralogy of the Ores.

The iron-ore minerals which occur in the iron-ore area are :—

Magnetite (Fe_3O_4), which contains 72·4 per cent. of iron.

Hematite (Fe_2O_3), which contains 70·0 per cent. of iron.

Martite (Fe_2O_3), usually pseudomorphous after magnetite.

Siderite ($FeCO_3$).

Limonite and other hydrated ores, which contain 59 to 66 per cent. of iron.

Titaniferous ores.

Practically the whole of the ore that occurs and is mined in the area is hematite of various types, but, of course, it is almost impossible to prevent a certain admixture of hydrated material during mining operations.

The ores and the banded hematite-quartzite are often slightly magnetic, but this is probably due to a small admixture of magnetite. Small octahedral crystals of magnetite, often converted into martite, are fairly common in some of the banded hematite-quartzite and ore layers. As far as I know, no quantity of magnetite occurs in any of the ore-bodies, but there is one small isolated solid ore-body of magnetite near Badampahar (22° 05′ : 86° 07′) in Mayurbhanj State.

Laterite which contains up to, say, 45 per cent. of iron is abundant in the area, and a small amount gets shipped with the ore.

Minerals that occur in very small quantity with the hematite are quartz, kaolin, pyrite, apatite and calcite.

Character of the Ores.

The hematite varies from a massive steel-grey type containing over 69 per cent. of iron, through a porous laminated shaly-looking type running to over 60 per cent. of iron, to a fine soft powder which runs up to over 69 per cent., and will probably average well over 65 per cent. of iron. The porous laminated type at the surface is often somewhat hydrated and often has a lateritic appearance.

There is usually no sharp line of division between the different types and the one seems to pass gradually into the other.

The following varieties of hematite ore may be recognised :—

(1) Massive hematite.
(2) Laminated hematite.
(3) Powder hematite.
(4) Lateritic hematite.
(5) Hematite-breccia.
(6) Consolidated hematite debris.

Massive hematite.

(1) The massive ore, which is practically pure hematite, has a steel-grey colour, often with a metallic lustre, and is usually extremely fine-grained, dense and compact. It has a metallic ring when struck with a hammer. This ore has a specific gravity of about 5·0 and specimens have yielded on assay 70 per cent. of iron, whilst samples of exposures of the massive ore yield over 66 per cent. of iron.

This massive ore often forms steep cliffs, which are well seen at Joda in Keonjhar State (see Plate 21), and also in the southern part of the Noamundi-Kotamati deposit on the Singhbhum-Keonjhar boundary.

The ore is well bedded, but is often broken into blocks by joint planes. At the surface this type of ore often has a polished appearance, and is sometimes coated with a greyish black film. It is very resistant to weathering, but along the edges of blocks a certain amount of rounding takes place owing to solution. Solution and alteration also take place along the bedding and joint planes and often result in the formation of thin bands of lateritic material in the solid ore. This solution and alteration of the massive ore can in some cases be seen to cause a passage into a laminated shaly-looking ore (see Plate 26, fig. 1). These massive ores occupy about eight cubic feet to the ton, but in my estimates ten has been taken as the lowest figure, in order to allow for interbedded porous laminated ore, and for slight lateritic alteration.

When seen in thin section, the ore is grey and metallic and often resembles magnetite; but it usually has a slightly reddish tinge by reflected light.

Laminated hematite.

(2) The laminated hematite varies in character, from a solid reddish type through a solid grey laminated variety, which is dense and compact, with a metallic ring under the hammer, and might almost be classed with

the massive ore, to a less solid laminated variety, which is often inclined to a shaly appearance, and is often extremely porous. This shaly appearance is usually due to thin laminæ of the massive grey variety being interbanded with thin laminæ of less compact ore, often of a reddish colour and usually very porous. The spaces in the porous varieties occasionally have small grains of white quartz, or white, or ferruginous shaly and kaolinic material in them. The bedding in this type of ore is usually well marked, but owing to the leaching out of much of the original material in the rock, the ore is often very contorted and broken up into small fragments, either by earth movements or by the weight of overlying material. Cavities sometimes occur in this type of ore. It is found in working that if the more shaly and poorer material which may only contain, say 56 per cent. iron, is hand screened, a large part of the impurity passes away with the fines, and ore containing over 60 per cent. of iron is obtained.

Leith and Harder[1] state that the porosity of similar ores in Brazil is due probably to the leaching out of carbonate and perhaps some silica.

The specific gravity varies considerably, depending on the proportion of the massive ore and the amount of porosity, and varies from about 3·5 in the earthy varieties to about 5·0 in the solid laminated types. Owing to their porous nature these ores often become hydrated, and tend to become lateritised. This type varies in density from about ten to twelve cubic feet to the ton, ranging up to fifteen cubic feet, when very porous. As would be expected, the iron content varies considerably, but is usually well over 60 per cent., and in some of the denser type approaches very closely to that of the massive varieties.

This laminated ore can be seen in places to pass laterally into the ordinary banded hematite-quartzite. Attention was first drawn to this passage in my Progress Report[2] for 1918-19 as occurring at Sasangda and other places in the main iron-ore range. Examples of this passage have also been exposed in the recent mining operations on Hills 1, 2 and 3 at Noamundi mine (see Plates 25 and 26).

There seems to be no doubt that this type of ore has resulted mainly from the leaching out of silica from the banded hematite-quartzite.

[1] *Econ. Geol.* VI, p. 675, (1911)
[2] Manuscript report, *Geol. Surv. Ind.*, (1919).

There is also a type of laminated shaly ore which has resulted from the alteration of the shales. This type may be very rich, running to well over 60 per cent. of iron, but it gradually passes into the usual shales of the area.

Powder hematite.

(3) The powdery variety is usually so fine-grained and unconsolidated that it falls into powder at a touch, but it usually contains some lumps or bands of harder ore. This powder ore can been seen in parts of most of the areas where mining or quarrying operations have taken place, and is well exposed in some of the workings of the Bengal Iron Company at Pansira Buru, near Duia, where some 80 feet or so of hard ore has been removed. Tunnels put into the hill in Buda Buru, near Chiria, for a distance of some 150 feet are almost continuously in this soft powder ore. It has also been encountered at the Noamundi mine, at Gua, at some of Messrs. Bird and Co.'s workings near Barabil, and to the north-west of Bolani.

Although usually containing over 65 per cent. of iron, it is of very little use at present, and is looked on with disfavour by the blast-furnace operators, as the material tends to choke the blast-furnace or get blown out into the flues. The powder, which in the mass is dark blue-grey in colour, consists mainly of grey, ragged, irregular shaped fragments, with flakes of red transparent micaceous hematite: occasional octahedral crystals occur, which appear to be mainly martite, but a very small proportion of these crystals are magnetic.

Dr. Fermor[1] stated in 1919 :—

'Such development work as has yet been done in Singhbhum and Gua indicates however that below the compact hematite lies friable micaceous hematite.'

A striking feature of some of these soft powder deposits is the occurrence in them of thin beds of white clay-like material. This feature can be well seen in the tunnels noted above, and also on the east side of the main range near the top bunker of the Gua workings. The soft ore is only occasionally exposed at the surface, and when so exposed, it is usually due to a slip of ground or to cutting by a hill stream. An exposure of this type was seen in the stream (Raikichri Lor) cutting at about the 2,000 feet contour on the west side of the Gua main range.

The soft powdery hematites of India have been very little opened up, and therefore few screen tests have been carried out on them.

[1] *Proc. As. Soc. Bengal*, XV, p. clxxx, (1919).

The following table shows the results of a series of sieve tests made by me :—

TABLE 1.—*Results of Screening Tests on powdery hematites.*

Size of mesh.	1	2	3	4	5	6	7	8
Above 8-mesh	25·2	18·5	28·9	9·0	10·9	23·2	37·0	31·0
„ 20 „ below 8-mesh . .	8·1	6·9	13·0	11·3	10·4	11·6	16·1	12·0
„ 40 „ „ 20 „ . .	8·8	4·5	9·4	15·5	15·6	12·4	11·0	9·0
„ 60 „ „ 40 „ . .	5·2	3·0	5·6	9·8	10·0	8·1	7·1	4·6
„ 80 „ „ 60 „ . .	2·6	3·0	6·6	7·3	9·6	6·4	4·9	3·5
„ 100 „ „ 80 „ . .	1·6	1·7	1·8	5·4	8·3	18·8	2·0	0·9
Below 100-mesh	48·5	62·4	34·7	41·7	34·6	19·4	21·8	38·9
TOTAL .	100·0	100·0	100·0	100·0	99·4	99·9	99·9	99·9

No. 1. Typical blue dust hematite from Noamundi.
No. 2. Typical blue dust hematite from Buda.
No. 3. Coarse blue dust hematite from Buda.
No. 4. Typical blue dust hematite from Gua (long incline).
No. 5. Typical blue dust hematite from Gua (long incline).
No. 6. Blue dust with hardish bands from Gua (near top bunker).
No. 7. Blue dust with hardish bands from Gua (near top bunker).
No. 8. Coarse blue dust hematite from Pansira.

For the purpose of these sieve tests, samples of about fifty pounds were reduced to about five pounds, which was put through the sieves. The iron content of some of the grades was determined in the Geological Survey Laboratory on the dried sample No. 4 from Gua and the following are the results :—

	Per cent. iron.
Original material	69·53
Above 8-mesh	65·47
„ 20 „ below 8-mesh	67·02
„ 60 „ „ 20 „	68·37
„ 80 „ „ 60 „	69·62
„ 100 „ „ 80 „	68·60
Below 100-mesh	68·95

The original undried sample contained 0·275 per cent. of water.

I weighed a sample of the undried blue dust No. 4 ; this had become loose in handling, but it was gently tapped in the container,

and gave 164·5 lbs. to the cubic foot, or 13·7 cubic feet to the ton (2,240 pounds).

Dr. Percival of the Tata Iron and Steel Co., Ltd., gave me the following results of two screen tests made by him:—

	No. 1	No. 2
Over 16-mesh	31·6	17·62
Through 16 over 32-mesh	10·0	10·30
" 32 " 60 "	14·1	18·62
" 60 " 100 "	1·0	1·47
" 100 " 200 "	3·3	6·89
Below 200-mesh	40·0	45·10
TOTAL	100·0	100·00

He states that the only large material consisted of thin flakes up to half an inch square and perhaps one-sixteenth of an inch thick, which were picked out before the sieve tests were done. In consequence of this extreme fineness, some of the iron companies in India do not consider that this material should be included in their reserves of ore.

It was extremely difficult to get any definite information in India on the economic possibilities of these rich soft ores; but my visit to the Lake Superior ranges has convinced me that some part of these soft hematites should be included in the reserves of ore held by any mining company, and that the balance of this valuable material should not be wasted, but should be considered as a possible reserve for the future. The Mesabi ores contain a fair amount of coarse material, and it is found that about 70 per cent. is coarser than 40-mesh, whilst about 10 per cent. will pass through a 100-mesh. In India the soft hematites appear to be much finer-grained and there is only about 40 per cent. over 40-mesh, and usually something like 40 per cent. of the material will pass through a 100-mesh.

This powder-ore is at times seen to pass laterally into the friable laminated ore, and when looked at *in situ* in a mining face, it is difficult to imagine that it is a soft powder, but immediately it is touched, it falls to the ground as a powder. The lateral passage of laminated ore to powder-ore is shown in Plate 25, fig. 1, which shows one of the working faces at the Noamundi mine.

Lateritic ore.

(4) The lateritic variety occurs in large quantities throughout the iron-ore area, as a surface alteration product, sometimes of the iron-ore itself, at other times of the ferruginous shales, and at still other times of the hematite-

breccia or other rocks. Lateritisation is usually a surface feature, but attention has already been drawn to the formation of laterite bands along the joint and bedding planes of the massive hematite. The laterite is usually of too poor a quality and too rich in alumina to be of use as an iron-ore, though at times owing to the presence of fragments of unaltered hematite in the mass the iron content is nearly 60 per cent., and it becomes of economic value; but it usually runs to between say 40 and 50 per cent. of iron. These angular fragments of hematite are often found in the laterite, which has been formed by the alteration of the porous laminated type of ore, and in this type of alteration the laterite seems to break up the original hematite into fragments, which later occur lying at all angles in the laterite. At times the original bedding can be distinguished, and then it is known to some extent from what type of rock or ore the laterite has been derived, but at other times the lateritisation has been so complete as to obliterate all traces of the character and bedding of the original rock. Lateritisation increases the proportion of alumina to iron, and the lateritic ore is usually fairly high in phosphorus.

During the sinking of a prospecting pit in the Noamundi mine area, the coolies after opening up to a depth of about fifteen feet, suddenly broke through to an underground cave. The cave was about four feet high, but the distance to which it extended was not determined, owing to the narrowing down in its height. The pit was put down in a ferruginous lateritic material, and an analysis of this material made by the Tata Iron and Steel Co., Ltd., showed that it contains 30·5 per cent. of $CaCO_3$, the solution of which evidently accounts for the cavity. There appears to have been a narrow band which ran high in lime, as analyses of the surrounding laterite indicates it to be of the usual ferruginous type.

Similar caves to this may occur in the area, and it is a possible explanation of the hollow sound that is sometimes noted when walking over some parts of the iron-ore area, more especially some of the large lateritic plains.

Hematite-breccia.

(5) In my description[1] of the iron-ores of Singhbhum and Orissa, I included under hematite-breccia various types of ore, including the debris or talus material which accumulates on the slopes of hills, or in old stream

[1] *Rec. Geol. Surv. Ind.*, LIV, p. 210, (1922).

valleys, and which gets consolidated together. Also material which has been broken up by faulting and recemented. Also the true hematite-breccia which occurs interbedded in the iron-ore series. It has since been recognised that the term hematite-breccia should be used only for the latter type of ore.

This brecciated type of ore occurs at numerous points in the iron-ore area, and in some parts such as at Jiling Buru, near Gua, it forms an extremely valuable iron-ore. It is made up of fragments of hematite cemented together by hematite. Dr. Percival[1] says :—

> 'It has the appearance of having been broken up *in situ* and recemented whilst fresh supplies of iron oxide were still being brought in.'

The ore consists of angular fragments of solid blue-grey hematite, cemented together by a reddish brown dull-looking hematite, and often contains well over 60 per cent. of iron. Angular fragments of banded hematite-quartzite also occur, and when these are in large amount, the ore becomes too siliceous to be of economic value.

Consolidated debris.

(6) The consolidated debris is the cemented hematite boulder or pebble material which accumulates on the slopes of hills, in old river valleys, and on plains between the hills. It consists of rounded and angular fragments of solid and laminated hematite cemented together by lateritic and occasionally by hematitic material. It often forms small scarps or cliffs of conglomeratic material overlying rich hematite, banded hematite-quartzite, shale or other rock, so that a considerable amount of pitting may be necessary before it is possible to get an idea of the underlying rock for the estimating of quantities of iron-ore present. Plate 25, fig. 2, which was taken near the bear caves on the western slopes of Pachri Buru, Noamundi mine, shows this consolidated debris overlying rich laminated hematite. A similar type of material, but in which the fragments are largely banded hematite-quartzite cemented together by lateritic material also occurs, but is useless as an iron-ore.

Considerable amounts of this consolidated debris occurs in the iron-ore area, and it constitutes a rich and valuable type of ore, often containing well over 60 per cent. of iron.

The slopes of the hills in which the ore-bodies occur, and the ore-bodies themselves, are often partially covered with a thick layer of soil in which are scattered fragments and boulders of rich hematite

[1] *Trans. Min. Geol. Inst. Ind.*, XXVI, pp. 188-189, (1931).

at times mixed with fragments and boulders of banded hematite-quartzite. These debris deposits, known in the mining area as 'float', constitute a valuable and easily worked type of ore.

Quality of the Ore.

In the Quinquennial Review of Mineral Production for 1909-13 [1], an average analysis of the ore at Pansira Buru and Buda Buru is given :—

	Per cent.
Iron	64·00
Silica	3·00
Manganese	0·06
Phosphorus	0·05

This agrees fairly well with a number of analyses given me by the Tata Iron and Steel Co., Ltd., from samples collected from the deposits taken up by them, and shown in the following table :—

TABLE 2.—*Analyses of samples of Iron-Ore from South Singhbhum.*

—	Sasangda.	Jarida Buru, 18 samples.	Kotamati Buru, 19 samples.	Pachri Buru.	Dirisium Buru, 6 samples.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	64·3	63·74	63·33	63·94	62·95
Sulphur	0·015	0·019	0·030	0·024	0·018
Phosphorus	0·058	0·080	0·088	0·072	0·087
Manganese	..	0·104	trace	trace	trace
Titanium	..	trace	..	..	*nil.*
Insoluble residue	1·12	2·35	2·14	2·49	1·24

In the Sasangda deposit the phosphorus varies considerably up to a maximum of 0·103 per cent.

In the above mentioned 18 samples from the Jarida Buru area the phosphorus varied considerably from 0·038 up to 0·152 per cent.

[1] *Rec. Geol. Surv. Ind.*, XLVI, p. 105, (1915).
[2] *Trans. Min. Geol. Inst. Ind.*, XXVI, p. 189, (1931).

Two of the above samples from the Kotamati Buru area were tested for titanium, and gave 0·25 and 0·20 per cent. respectively.

Four samples from Pachri Buru, tested for titanium, only gave traces.

One of the above samples from Dirisium Buru gave 0·31 per cent. of titanium.

The average of samples taken by me from the deposits at Sasangda, Jarida, Pansira, Gua, etc., and assayed in the Geological Survey Laboratory, gave about 64 per cent. of iron. Samples of the hard compact ore from the better parts of the deposits often run up to 68 or 69 per cent. of iron.

The Iron-Ore Bearing Rocks.

The iron-ores as noted on page 196 occur mainly in the banded hematite-quartzite and to a less extent in the adjoining ferruginous shales, which have been partly converted into ore by local replacement.

The iron-ore of commercial value at the present time forms only a very small part of the iron-bearing rocks. Although it has not been accurately determined for the whole area, the results of the iron determined in a large number of samples and specimens shows that the iron content of the banded hematite-quartzite will probably average from about 28 to about 30 per cent.

This banded hematite-quartzite consists of interbanded layers of silica, iron oxide and intermixtures of the two. The rocks are converted into ores by local enrichment, mainly by the leaching out of silica, but in some cases there is a certain amount of iron introduced. All gradations between the banded hematite-quartzite and iron-ore occur.

Structure of the Ore-Bodies.

The ore-bodies are the result of alterations of some of the richer parts of the iron-bearing rocks, mainly the banded hematite-quartzites, but also occur as an alteration of some parts of the shales, and are mainly confined to those parts where the altering waters have the greatest circulation. This circulation depends on the geological structure, faults, impervious rocks, etc., and these, being very irregular cause the shape of the ore-bodies also to be very irregular. Little exploratory work has been done, so that com-

paratively little is known of the depth to which these alterations have gone.

Some of the ore-bodies, such as Pansira Buru, where mining operations have been going on for some years, are seen to be roughly tabular in shape, dipping at about 70°. The Noamundi ore-body was originally tabular in shape with a flat dip of, say 10°, but this is now broken up by a series of faults into a number of tabular bodies.

Faults are common in most of the iron-ore-bodies and have no doubt largely assisted in giving easy access to the altering solutions.

Distribution of the Iron-Ore.

The ore-bodies and the banded hematite-quartzite are the hardest and most weather-resisting materials in the area, and therefore the iron-ore usually occurs at or near the tops of hills or ranges of hills; but near Jamda, in the south of the Singhbhum district, and in the eastern part of the iron-ore area of the Keonjhar State, it is often found at very low levels, and in some cases actually in the plains themselves. The most important of these ranges of hills is the one that starts near Rontha (21° 46′ : 85° 08′) in the Bonai State, and continues to the N. N. E. to a point about three miles south-west of Gua, a distance of about thirty miles. Running more or less parallel to this range, and possibly faulted from it, are other smaller ranges which contain good iron-ore. The main range rises some 1,500 feet above the plain, and iron-ore averaging over 60 per cent. of iron occurs for practically the whole length of the thirty miles. A few small breaks occur, where the rock has not been replaced, or where folding has occurred, but these are negligible compared with the total length. The rocks forming this range dip at about 70° in a north-west to west direction, so that the width of the outcrop of the iron-ore gives practically the thickness of the ore-bodies.

Average Sample of Ore at Noamundi.

Dr. Percival states[1] that the average analysis of the ore despatched from the Noamundi mine does not correspond to the material *in situ*, as the fines below half an inch are rejected and these are high in silica and alumina.

[1] *Trans. Min. Geol. Inst. Ind.*, XXVI, p. 189, (1931).

A complete analysis of the average samples taken from a day's run of the Noamundi mine is given by him as follows:—

	Per cent.	
SiO_2	2·42	
FeO	2·45	(Fe=
Fe_2O_3	85·87	61·94)
Al_2O_3	4·31	
TiO_2	0·34	
MnO	0·11	
MgO	0·17	
CaO	0·35	
ZnO	*nil.*	
PbO	*nil.*	
CO_2	0·43	
Total alkalies	0·10	
Cr_2O_3	*nil.*	
V_2O_5	*nil.*	
CuO	0·010	
WO_3	0·004	
NiO	*nil.*	
CoO	*nil.*	
P_2O_5	0·188	(P – 0·082)
SO_3	0·024	
As_2O_3	*nil.*	
Combined water	3·26	
TOTAL	100·036	

In this analysis the alumina is higher than the average, due to the inclusion of some lateritic ore in the wagons.

Origin of the Iron-Ore.

The rocks in which the iron-ore occurs are, as previously stated, similar to those pre-Cambrian iron formations which occur in different parts of the world, and whose similarity was early recognised by the writer. The best known of these pre-Cambrian iron formations is that of the Lake Superior Region of the United States of America, where iron-ore was first mined in 1848. Much discussion has taken place on the origin of these iron formations, as noted on page 199, but it is generally believed that they were marine chemical sediments, though the source of the iron is still doubtful.

Dr. C. K. Leith stated[1] in 1924 :—

'Problems of distribution, structure, and secondary concentration of the iron ores in these formations have been pretty well solved, but the question of the ultimate source of the iron and the sedimentary processes which segregated them on such an immense scale is yet in the main unanswered.

The originally deposited materials are iron oxide, iron carbonate, iron silicates, more or less interbedded with chert or sand or other sediments. In the main they are clearly chemical sediments, to a slight extent organic and locally a small amount of fragmental deposition may be noted.

The fact that iron formations are not normal results of the common cycle of erosion and deposition exhibited in the geologic column, but are highly unusual, in itself shows that the process of accumulation must have varied in some essential particular from the process of normal weathering, transportation, and deposition which go to make up the common sediments.

It will be noted that the principal difficulties to be encountered relate to the source of such large amounts of iron salts, and to the transport processes which are able to segregate them so thoroughly, and not to the manner of precipitation from solution after they have been brought together. Simple and well known chemical processes such as oxidation adequately account for precipitation on a large scale; also organic agencies such as bacteria and algae are known to take part in this phase of the work.'

At a meeting of the American Institute of Mining and Metallurgical Engineers held in December 1931, Dr. Leith said :—

'Insolubility of silica is a myth. Silica is widely distributed through the rocks of the earth and a relatively great weight of silica, particularly in the form of silicates, is leached out in ordinary weathering processes. True its solution is facilitated by higher temperatures, but the absence of high temperatures puts no particular burden on the proof that cold solutions can dissolve without the excess heat. The difficulty is in explaining this loss of silica on the extremely large scale that must have been necessary for the formation of the extensive ore deposits of the Pre-Cambrian era.'

In my Progress Report for 1918-19, it was stated[2] that I considered that the ore-bodies are derived from these rocks (the banded hematite-quartzites) by local enrichment, largely by the leaching out of silica, and to a less extent by the introduction of iron oxide. The porous nature of a large proportion of the ores seems to indicate that they have been largely produced by the leaching out of the silica from the banded hematite-quartzites. The fine and irregular grain of the quartz in these rocks afford large surfaces for solution by percolating waters.

Nothing has been recorded in the area which suggest that organic agencies had any place in the precipitation or formation of the iron-ore.

[1] *Econ. Geol.*, XIX, pp. 382-385, (1924).
[2] General Report for 1919, *Rec. Geol. Surv. Ind.*, LI, p. 18, (1920).

Origin of the porous laminated ore.

The lateral passage of banded hematite-quartzite into iron-ore was recorded at several localities during the first season's work in the area, but this passage is more clearly seen in the faces produced during the mining operations at the Noamundi mine. There seems to be no doubt that the porous type of ore has been mainly formed by the leaching out of silica from the banded hematite-quartzite. There also seems to be no doubt that at times some secondary hematite has been brought in and deposited by meteoric waters, but generally speaking the spaces which were originally occupied by silica are now empty in this type of ore. This porous type of ore can be traced laterally into massive laminated ore and into massive ore.

In a mining face near the hospital at the Noamundi mine, the banded rocks can be seen passing laterally into shaly looking somewhat crumpled ore, and in the middle of this mass of ore is a horse of banded hematite-quartzite (*see* Plate 26, fig. 2). A similar horse was seen in one of the working faces of Hill 1, Noamundi mine. This change from banded hematite-quartzite to ore is mainly due to the leaching out of silica, but some of the iron has gone into solution and in the horse in Hill 1 noted above, some of it seems to have been redeposited, and to have replaced some of the silica of the original rock. There seems to be no doubt that in these cases there was a lateral passage from the banded quartzite into ore. During the leaching out of the silica, the hematite bands of the rocks were generally left unsupported; the weight of the overlying rocks, and possibly movement in the beds broke these bands down into slaty fragments which slumped and often lay in all directions, to be recemented to some extent by ferruginous material brought in later by percolating solutions.

In some cases the individual band of hematite in the banded hematite-quartzite can be traced into the ore, but often the ore has slumped to some extent, and the band cannot be followed far.

Some of the porous ore in this iron-ore area is certainly formed by replacement of the shales by the action of meteoric waters. At the Noamundi mine, the shale which underlies the banded hematite-quartzite is being mined and despatched. A gradual passage with increase in iron content, can be traced from the pale-coloured shale to an ore containing over 60 per cent. of iron. A similar example was recorded[1] by me in 1921, where on the lower slopes of Kala Parbat

[1] Unpublished manuscript, *Geol. Surv. Ind.*, (1921).

in Keonjhar State, nearly white shale becomes more and more stained and replaced by iron oxide which has been deposited from iron bearing solutions, until the rock eventually becomes rich enough to be classed as an iron-ore. Dr. Percival[1] considers the massive ore to have been deposited originally in its present form, and that it is not a replacement ore.

Origin of the massive ore.

The massive ore is closely associated with the porous laminated ore. and there is no doubt that the one type can be traced laterally into the other, and eventually into soft powder ore and banded hematite-quartzite. This suggests that these different types of ore and rock were formed in a similar manner.

It has been shown on page 243 that the porous laminated ore has been formed mainly by the leaching out of the silica of the banded hematite-quartzite, and to a less extent by the replacement of this silica by iron oxide. There is no doubt that there is a certain quantity of secondary hematite in the rocks. At first it was considered that these massive ores resulted from the metasomatic replacement of the silica in the banded hematite-quartzite.

These massive ores show alternating layers of slightly varying type, some of the layers being slightly porous. These ores have only been opened up to a small extent, so there have been few opportunities of seeing any residual silica in them. If these massive ores have been partly formed as has been suggested by the replacement of the silica in the banded hematite-quartzite, then there must have been considerable movement of meteoric waters which would undoubtedly have dissolved and carried away all the silica in the ore. There is no doubt that meteoric waters carrying ferruginous material, has deposited some secondary hematite in the rocks and ore-bodies. These massive ore-bodies may possibly not have been formed by metasomatic replacement; but there seems to have been an introduction of secondary hematite, which occupies the space that was once occupied by silica.

Origin of the powder ore.

The powder type of ore was originally considered to be a chemical precipitate which had been formed suddenly by some marked change in the conditions under which the iron was held in solution. It was difficult to account, however, for its remaining in this powdery

[1] *Loc. cit.*, p. 241, (1931).

condition since pre-Cambrian times. Later, after seeing examples of this powder ore passing laterally into the porous and massive laminated ore, it was concluded that they must all have been formed in the same way, and that is by the leaching out of silica from the original rock, leaving the finely divided hematite as a powder. The harder consolidated bands in the powder would represent bands in the original rock that contained less silica than most of the rock. The powder ore is similar in appearance to the porous laminated ore, and from a few yards away it is sometimes difficult to say which type of ore is exposed, but the powder ore when touched, falls down as an unconsolidated powder.

On Bonamuli Buru, near Gua, and at other places, thin white bands of shale or kaolin occur interbedded with the powder. It is difficult to understand why these thin bands of white shaly material should remain so unaffected in the middle of the powder, whilst such large quantities of silica have been leached out of the rock; also why the percolating solutions have not consolidated the powder to a greater extent.

CHAPTER III.

ESTIMATES OF QUANTITIES OF IRON-ORE.

Introduction.

Work in the iron-ore area of Singhbhum was commenced in November, 1918, but after a few months work it was realised that it would be impossible to get more than a very rough idea of quantities of iron-ore available in the area. In December, 1918, I reported after examining the hills near Pansira Buru, Raijori Buru, etc., that large exposures of rich iron-ore were comparatively rare, owing to the soil-covered and forest-clad hill-slopes, and to the lateritisation of the ore-bodies at the surface. Large cliffs and exposures of rich hematite are, however, sometimes seen in the larger and more massive ore-bodies. Rich boulders of hematite and exposures of laterite may, or may not, indicate the presence of good iron-ore, and a considerable amount of pitting, trenching and drilling is necessary in order to prove an ore-body.

In making estimates of the quantities of iron-ore available, one of the main points is to decide what is to be considered an iron-ore. Material which would be considered rich iron-ore in some other countries might be considered useless by the iron-smelting companies in India. My calculations were made on ore which I considered averaged not less than 60 per cent. of iron, and no attempt was made to exclude thin bands or small patches of material which were slightly below 60 per cent. of iron, but which when mined with the mass, would average not less than 60 per cent. of iron.

It was recognised quite early in the investigation that the hard hematite would probably pass into softer or powder hematite in depth. There was practically no information as to what depth the hard ore extended, as very little prospecting work or opening up of the deposits had been carried out, so it was impossible to give separate estimates for hard and powder ores, and therefore no special attempt to exclude these rich powder ores was made.

For the estimation of quantities and for the mapping of the iron-ore, the Forest Survey maps of Singhbhum on the scale of four inches to the mile, are very good. For the Bonai and Keonjhar States, however, the best maps available were the Bihar and Orissa sheets on the scale of one inch to two miles for a small area of the States. For the remainder of the area in these States, the best maps were the old Bengal Survey sheets on a scale of one inch to a mile, done about 70 years ago. These maps are not contoured, and are not very accurate. New maps of the iron-ore area on the scale of one inch to the mile have been prepared, and were used by Dr. Krishnan in his re-survey of parts of Keonjhar and Bonai States, and in his estimation of quantities of iron-ore available.

Maps available.

The estimates have been made almost solely from surface observations. In all cases the figures, except where otherwise stated, refer to ore-bodies averaging not less than 60 per cent. of iron, and should be looked on as the minimum quantity of ore in the ore-body referred to. A large part of some of these ore-bodies will probably prove to be powder ore, but it is quite impossible to give separate estimates for this from the information at present available. The only area that has been fairly thoroughly prospected is the Kotamati ridge of the Tata Iron and Steel Co.'s Noamundi mine, where the Company has put down 42 bore-holes, hundreds of prospecting pits, trenches, etc. The result of this work has been given by Dr. Percival[1], and he has separated the iron-ore into two grades :—

Methods of estimation.

> Grade A, which means ore that can be economically worked at the present time.
>
> Grade B, includes the powder ore, and ore which he considers economically unworkable.

In this Noamundi mine area, Dr. Percival's figures show that only about 60 per cent. of the total ore is Grade A. In the Lake Superior area of America, the practice of sintering soft powdery ores is increasing, but it is doubtful if it would be economically possible to sinter the Indian soft ores, whilst hard ore is available. It is possible, and highly probable, that new methods of treatment of such ores will be developed in the future, so that most of his

[1] *Trans. Min. Geol. Inst. Ind.*, XXVI, pp. 169-271, (1931)

Grade B ore may be looked on as a possible reserve for the future.

The number of cubic feet of ore that goes to a ton depends to a great extent on the porosity of the ore, and the figure used in making the estimates is largely a matter of judgment. For the solid massive ore, in no cases has less than ten cubic feet of ore to the ton been taken, although theoretically seven cubic feet of solid hematite goes to the ton, and there seems little doubt that parts of some of the ore-bodies, such as Kotamati Buru, Pachri Buru, Joda East, parts of Sasangda, etc., will probably very nearly equal the theoretical figure. In the porous shaly-looking ores, about 12 to 15 cubic feet has been taken to the ton of ore.

In the case of certain hematite debris areas, it is probable that the debris covers solid ore, but prospecting pits or other means are necessary to prove this. In these debris deposits, an average thickness of five feet has been taken, and from 30 to 50 cubic feet of ground to the ton of ore.

It is impossible to say what happens below the surface with ore-bodies that have been formed in the manner that most of the ore-bodies in this area are supposed to have been formed, *viz.*, by the leaching out of silica from the banded hematite-quartzite, and to a less extent by the replacement of the original rock by iron oxide; but it is difficult to imagine a big ore-body such as in the main iron-ore range, where the rocks and ore dip about 70° to the north-west, and the ore is almost continuous for a length of 30 miles, with a breadth varying from 400 to nearly 1,000 feet, dying out in a short distance below the surface. I have no doubt, therefore, that ore will be found in parts to extend to many hundreds of feet in depth, but, of course, borings or other prospecting work is necessary to prove this. The slopes of hills where the ore occurs are usually covered, and it is only occasionally from observations of height between the ore at tops of hills, and the same bed of ore in streams cutting or running away from these hills, that it is possible to get an idea as to the depth to which ore extends. In no case, however, has more than 200 feet below the surface been considered as ore, although from differences of height, as much as 700 feet have been observed.

Ore considered useless at the present time, may be an extremely valuable asset in the future. It is certain that as the supply of

hard rich ores become worked out, the use of poorer quality ores to mix with the remaining rich ores will increase. The banded hematite-quartzite itself will no doubt be used eventually when the richer ore becomes exhausted.

In the Lake Superior area of the United States, the grade of the ore being smelted is gradually getting lower. There are still large quantities of hard rich ore available, but lower grade ore is being mined and mixed with the rich ore, to give an ore which is just economically workable, and thus extend the life of the ore deposits. In this same area, some ores which average say 45 per cent. iron, and which in the past were considered useless as an ore, are now being concentrated by washing, and thus gives an increase in the amount of reserves available.

It will be seen from the above remarks that any estimates of reserves depend partly on a number of uncertain factors, and a difference of opinion on some of these factors may give rise to considerable variations in estimates made by different workers.

Distribution of the iron-ore.

The major part of the iron-ore seems to be fairly evenly divided between Singhbhum district, the Bonai State and the Keonjhar State. I have not estimated the quantity of iron-ore in the Mayurbhanj State, but there is supposed to be about 18,000,000 tons of ore available.

The following table gives an approximate idea of the quantities of iron-ore available in the iron-ore areas, but it is impossible to give any idea of how much of this will be hard ore, and how much soft ore :—

	Tons.
Singhbhum district	1,047,000,000
Bonai State	648,000,000
Keonjhar State	988,000,000*
Mayurbhanj State	18,000,000
TOTAL .	2,701,000,000

In the tables on pages 250 to 260 are given estimates made on the quantities of iron-ore occurring in the different ore-bodies of the area. The position of the ore-body referred to may be obtained by noting its number and referring to the map (Plate 32). In these tables, the column which gives the thickness in feet, refers generally to the continuation of the ore in depth below the surface.

* Another, higher, estimate is given on page 258.

Singhbhum District.

TABLE 3.—*Estimates of Iron-Ore in South Singhbhum.*

Ore-body.	Area in square feet.	Thick-ness in feet.	Cubic feet per ton.	Quantity in tons.
1. Kotamati Buru, north area . .	2,895,500	30	15	4,791,000
,, ,, south area . .	25,155,900	70	10	176,091,000
2. Pachri Buru	13,312,000	50	10	66,560,000
3. Bond Buru, south area . . .	1,518,000	40	12	5,060,000
,, ,, north area . . .	1,524,600	30	15	3,049,000
4. Lagirda Buru	1,960,200	50	15	6,534,000
5. Bai Buru	1,306,800	40	15	3,485,000
6. Hatu Gutu	2,940,300	30	15	5,881,000
7. Chariapat Buru	2,613,600	30	15	5,227,000
8. Maha Buru (2 areas) (*a*) . . .	217,800	20	15	290,000
,, ,, ,, (*b*) . . .	217,800	20	15	290,000
9. Hill 1,750 feet (Baljori) . . .	980,100	20	15	1,307,000
10. Notu Buru	316,800	75	12	1,980,000
11. Pansira Buru	792,000	150	12	9,900,000
12. Banalata Buru, south of Pansira Buru	792,000	50	12	3,300,000
13. Ankua, Buda Buru	34,848,000	50	12	145,200,000
14. ,, Bogordui Buru . .	6,969,600	50	12	29,040,000
15. Marang Ponga	2,112,000	30	15	4,224,000
16. Dirisum Buru	3,168,000	100	12	26,400,000
,, ,, debris	6,936,000	5	30	1,156,000
17. Hokolata Buru	2,100,000	80	12	14,000,000
18. Jalamjal Buru, north of Burai Buru .	300,000	20	12	500,000
19. Chatua Buru	168,000	20	15	224,000
,, ,, debris	2,100,000	5	30	350,000
20. Jarida Buru, south area . . .	800,000	30	15	1,600,000
,, debris, east side . . .	1,200,000	5	30	200,000
,, ,, west side . . .	2,640,000	5	30	440,000
21. East of Idri Buru	750,000	20	15	1,000,000
,, debris south-west and east of Idri Buru East body.	2,475,000	5	30	413,000
Carried over .	..	..	..	518,492,000

TABLE 3.—*Estimates of Iron-Ore in South Singhbhum*—contd.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	518,492,000
22. East of Jarida Buru	2,112,000	30	15	4,224,000
,, debris, east side .	2,772,000	5	30	462,000
,, ,, west side .	1,848,000	5	30	308,000
23. Jarida Buru	1,056,000	20	15	1,408,000
,, ,, debris	871,200	5	30	145,000
24. Durbar Buru to north boundary .	12,196,800	100	12	101,640,000
25. Baya Buru	520,000	30	15	1,040,000
26. Jiling Buru	1,200,000	20	12	2,000,000
27. Duargula Buru	633,600	30	12	1,584,000
28. No. 10 boundary to Ajiti Buru . .	7,128,000	100	12	59,400,000
29. Body east of ore-body No. 28 . .	2,640,000	20	15	3,520,000
30. Jirupai Buru, near Baraiburu, upper ore-body.	3,960,000	40	12	13,200,000
,, lower ore-body . . .	6,336,000	50	15	21,120,000
31. Sasangda north of Maghahatu Gara .	17,556,000	100	12	146,300,000
,, south of Maghahatu Gara .	11,286,000	100	10	112,860,000
,, east of main ore-bodies .	8,448,000	40	12	28,160,000
32. Tatiba, upper ore-body . . .	2,112,000	50	12	8,800,000
33. ,, lower ore-body . . .	5,280,000	50	12	22,000,000
34. Silpui (Jamda), debris . . .			say	400,000
TOTAL .	..	..	..	1,047,063,000

Keonjhar State.

TABLE 4.—*Estimates of Iron-Ore in Keonjhar State.*

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
1. South end of Kotamati Buru . .	6,969,600	40	10	27,878,000
2. South end of Pachri and Lagirda Burus	3,484,800	40	12	11,616,000
3. Included in Singhbhum No. 7 . .	..	..	..	..
Carried over .	..	..	..	39,494,000

TABLE 4.—*Estimates of Iron-Ore in Keonjhar State*—contd.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward	..	..	..	39,494,000
4. Thakurani (a) east ore-body	13,939,200	40	12	46,464,000
„ (b) middle ore-body	15,681,600	70	10	109,771,000
„ (c) west ridge, south ore-body.	5,227,200	40	10	20,909,000
„ „ north ore-body	13,939,200	50	10	69,696,000
„ consolidated debris	10,454,000	10	15	6,969,000
„ debris			say	6,400,000
„ south of middle ore-body	2,112,000	40	10	8,448,000
5. Jhargaon (2 areas)(a)	1,500,000	20	12	2,500,000
„ (b)	450,000	15	15	450,000
6. Jhargaon, north-west area	1,584,000	30	15	3,168,000
„ debris, north-west side	1,440,000	5	30	240,000
Other debris near Jhargaon	15,000,000	5	30	2,500,000
7. Sidhamat Parbat (a) northern	..	50	12	12,800,000k
„ „ (b) southern	..	50	12	12,200,000k
„ „ (a) and (b) debris	..	4	35	200,000k
8. Durga Parbat	3,000,000	20	10	6,000,000t
„ „ debris	3,000,000	5	50	300,000t
Area north of Durga Parbat	1,500,000	15	20	1,125,000t
„ „ „ debris	540,000	5	50	54,000t
9. Joda West, Surjat Parbat, mostly debris (includes ore-body 21).	30,000,000	5	40	3,750,000
9a. Bhaliathori Pahar, debris	27,878,400	5	30	4,646,000
10. Joda East (Bara Parbat ridge)	12,000,000	100	10	120,000,000
„ debris, west side	12,672,000	5	30	2,112,000
„ debris, north, south and east sides.			say	6,500,000
11. Banspani Pahar	3,360,000	150	10	50,400,000
East of Joda East (boundaries uncertain).	264,000	20	20	264,000
12. Dal Pahar	1,080,000	50	12	1,500,000
North of Kurband	5,000,000	20	10	10,000,000
13. Jiling Pahar	..	30	12	7,700,000k
„ „ debris	..	5	40	700,000k
Carried over	..	..	..	560,260,000

TABLE 4.—*Estimates af Iron-Ore in Keonjhar State*—contd.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	560,260,000
14. Langalota Pahar	3,000,000	30	10	9,000,000
,, ,, debris . . .	6,000,000	4	40	600,000
15. West of Kurband	11,700,000	20	10	23,400,000t
,, debris . . .	40,000,000	5	40	5,000,000t
North-east of Satkutnia Pahar .	4,000,000	50	10	20,000,000
16. Guali-				
(a) South of Burpoda . . .	2,640,000	20	12	4,400,000
,, debris	10,454,400	5	30	1,742,000
(b) Hills between Guali and Godabudini.	13,939,200	5	30	2,323,000
(c) Boundary between Burpoda and Kalmang.	1,980,000	30	12	4,950,000
17. 1½ miles north-east of Bhadrasai (2 areas) (a).	1,584,000	10	30	528,000
,, ,, (b)	1,584,000	10	30	528,000
Debris between Bhadrasai and Raikora	3,960,000	5	30	660,000
18. Kala Parbat, east of Bhadrasai .	2,000,000	20	20	2,000,000
19. Between Raikora and Borita (a). .	240,000	24	12	480,000
,, (b) .	234,000	40	12	780,000
20. Siahamat Parbat, mainly debris .	1,080,000	10	40	270,000
21. Included in No. 9	..	..	..	..
22. West of Banspani	1,800,000	20	12	3,000,000
North of Joloburi	3,600,000	20	12	6,000,000
North-west of Joloburi	3,600,000	20	12	6,000,000
23. Between Kurband and Joruri, south area	600,000	20	10	1,200,000
,, north area, mainly debris .	6,000,000	5	50	600,000
,, middle area, mainly debris .	6,000,000	4	40	600,000
South of Kurband	6,300,000	15	10	9,450,000
,, debris	12,000,000	5	30	2,000,000
24. North-west of Satkutnia Pahar .	1,200,000	20	15	1,600,000
25. Tiring Pahar	450,000	20	15	600,000
26. Kundrupani and Chur Malda (4 areas)	..	12	15	900,000k
,, ,, ,, debris .	..	5	40	100,000k
Carried over .	..	..	..	668,971,000

TABLE 4.—*Estimates of Iron-Ore in Keonjhar State*—contd.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	668,971,000
27. Guali—				
(a) Hill east of Guali . . .	2,376,000	5	30	396,000
(b) Hill west of Laidapoda . .	6,969,600	5	30	1,162,000
(c) West of Guali . . .	7,920,000	5	30	1,320,000
(d) North of Guali . . .	3,960,000	5	30	660,000
(e) North of Kendudi . . .	6,336,000	5	30	1,056,000
(f) Hills between Guali and Burpoda.	6,969,600	5	30	1.162,000
28. Satkutnia Pahar	4,000,000	50	10	20,000,000
29. Between Gurda and Gonua . .	1,000,000	10	10	1,000,000
,, ,, ,, debris .			say	1,000,000
30. North-west of Joribar . . .	390,000	20	12	650,000
,, debris . . .	810,000	4	40	81,000
West of Joribar	270,000	20	12	450,000
31. South-west of Joribar . . .	270,000	20	12	450,000
32. North of Joribar	600,000	20	10	1,200,000
33. South-east of Joribar (2 areas) (a) .	720,000	30	12	1,800,000
,, (b) .	90,000	20	10	180,000
,, debris . . .	4,500,000	5	50	450,000
34. Palsa, north area	1,200,000	20	12	2,000,000
35. South-east of Palsa . . .	360,000	20	12	600,000
,, debris . . .	3,600,000	5	50	360,000
36. South-east of Kunipos, north area .	270,000	10	15	180,000
,, south area .	40,000	10	20	20,000
,, debris .			say	50,000
Boradha East, north area . .	270,000	15	12	338,000
,, south area . . .	270,000	15	12	338,000
,, debris			say	120,000t
37. Maha Parbat	360,000	50	15	1,200,000t
,, ,, debris . . .			say	50,000t
45. East of Mitihurda	15,840,000	40	12	52,800,000
46. South-east of Mitihurda (2 areas) (a)	5,280,000	40	12	17,600,000
,, ,, (b) .	5,280,000	40	12	17,600,000
Carried over .	..	..	..	795,244,000

TABLE 4. —*Estimates of Iron-ore in Keonjhar State*—concld.

Ore-body.	Area in square feet.	Thick-ness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward	..	..	..	795,244,000
47. Diring Buru, east of Kadolia	2,640,000	40	12	8,800,000
48. South of Diring Buru	1,000,000	50	10	5,000,000
49. Ranga Parbat	2,400,000	50	12	10,000,000
50. Between Churisai and Loiaboga	..	50	15	2,788,000k
,, ,, ,, debris	..	5	40	279,000k
51. South of Mitihurda	4,000,000	40	12	13,333,000
52. Included with No. 29	..	..	..	..
53. Mankarnacha Peak	3,960,000	40	12	13,200,000
54. West of Kasijoda (a)	360,000	20	10	720,000
(b)	4,000,000	10	20	2,000,000
55. Ganda Mardan north-west area	2,250,000	20	10	4,500,000t
,, ,, top of ridge	2,000,000	15	15	2,000,000t
,, ,, debris	20,000,000	5	50	2,000,000t
56. North-west of Bar oli	150,000	20	15	200,000
Between Ulburu and Bilkundi (a)	200,000	20	15	267,000
,, ,, (b)	200,000	20	15	267,000
Debris between Ulburu and Barabil	13,200,000	5	50	1,320,000
57. Sasangda (Keonjhar side)	16,632,000	50	12	69,300,000
,, (a) middle area	1,156,000	30	12	2,890,000
(b) lower or Panposh body	12,830,400	50	12	53,460,000
TOTAL	..	..	..	987,568,000

k Estimated by Dr. Krishnan.
t = Estimated by Capt. Teychenné.
Ore-bodies 24, 28, 29, 40, 41, 43 and 45 are on the Bonai-Keonjhar boundary, but most of the ore is in Keonjhar State.

TABLE 5.—*Dr. Krishnan's estimates of Iron-Ore in Keonjhar State.*

Locality of deposit.	Area in hundredths of a square mile.	Thick-ness in feet.	Cubic feet per ton.	Quantity in tons.
1. Noamundi main	60	100	10	167,270,000
,, float	8	5	35	319,000
2. Murgabera boundary (2 areas)	19	60	10	31,781,000
Carried over	..	..	..	199,370,000

TABLE 5.—*Dr. Krishnan's estimates of Iron-ore in Keonjhar State* —contd.

Locality of deposit.	Area in hundredths of a square mile.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	199,370,000
3. Thakurani village	5·5	20	12	256,000
4. Thakurani Pahar (*a*) western ridge .	60	112·5	10	188,179,000
,, ,, ,, float .	20	8	30	1,487,000
,, ,, (*b*) middle ridge .	48	62 5	10	83,635,000
,, ,, (*c*) eastern ridge .	30	55	10	45,999,000
(*b*) and (*c*) float .	8	6	35	382,000
5. Between Burpoda and Jhargaon (3 smaller areas).	5	25	12	2,904,000
6. Between Burpoda and Jhargaon (2 larger areas).	20	37·5	12	17,424,000
7. Sidhamat Parbat (*a*) northern 2 areas	11	50	12	12,778,000
,, ,, (*b*) western 2 areas	10	50	12	11,616,000
,, ,, (*a*) and (*b*) float .	5	4	35	159,000
8. Durga Parbat	14	50	12	16,262,000
,, ,, float	20	6	40	836,000
9. Surjat Parbat	14	50	12	16,262,000
,, ,, float	8	5	40	279,000
Bhaliathori Pahar : float . . .	22	6	40	920,000
10. Bara Parbat	43	125	10	149,846,000
,, ,, float	13W + 30E	9	30	3,596,000
11. Banspani Pahar	64	125	10	223,027,000
,, ,, float	25	6	30	1,394,000
12. Dal Pahar	25	60	12	34,848,000
,, float	10	5	35	398,000
13. Jiling Pahar	11	30	12	7,667,000
,, ,, float	2	5	40	70,000
14. Langalota Pahar	11	62·5	10	19,166,000
,, ,, float . . .	6	6	30	335,000
15. Kurband and Satkutnia (4 areas) .	65	75	12	113,256,000
,, ,, ,, float .	10	5	30	465,000
16. Gendalpoda	18	15	15	5,018,000
,, float	7	5	40	244,000
17. Bhadrasai (manganiferous ?) . .	10	20	15	3,717,000
Carried over .	..	..	..	1,161,795,000

TABLE 5.—*Dr. Krishnan's estimates of Iron-ore in Keonjhar State* – contd.

Locality of deposit.	Area in hundredths of a square mile.	Thickness in feet	Cubic feet per ton	Quantity in tons
Brought forward .	..	..	..	1 161,795,000
18. Kala Parbat	8	20	15	2,974,000
19. Raikora	6	25	12	3,485,000
,, float	2·5	5	35	100,000
20. Sidhamat Parbat (Shaly) . .	10	20	12	4,646,000
21. Kamarjora	2	25	14	996,000
,, float	5	5	45	155,000
22 Between Jolohuri and Banspani(4 areas)	38	30	12	26,484,000
,, float	12	5	40	118,000
23 Between Kurband and Joruri (4 areas)	18	25	12	10 454,000
24 Satkutnia west branch	7·5	37·5	15	5,227 000
25 Tiring Pahar . . .	3	15	12	1,045,000
26. Kundrupani and Chur Malda . .	4	12·5	15	929,000
,, ,, ,, float . .	3	5	40	105,000
27. Around Guali	15	12·5	15	3 485 000
,, ,, float	9	5	40	314,000
28. Satkutnia Pahar (Bonai) . . .	5	75	12	8,712,000
29 South of Satkutnia on Bonai border .	3	15	15	836,000
,, ,, float . .	4	6	30	223,000
30 West of Joribar (2 areas in shale) .	12	12·5	25	1 673,000
31 South-west of Joribar . . .	4	15	12	1,394,000
,, float	3	5	30	139,000
32. North of Joribar . .	3·5	12·5	15	813,000
,, ,, float . . .	5	5	30	232 000
33. South-east of Joribar (2 areas) . .	7·5	20	12	3,485,000
,, ,, float .	4	6	35	191,000
34. Palsa	2	15	12	697,000
,, float	4	5	30	186 000
35. Bamebari	4	30	10	3,345,000
,, float	4	5	30	186,000
Konupus : float	2	5	40	70,000
36. One mile east of Palsa . . .	11	50	12	12,778,000
,, ,, float . . .	5	6	30	279,000
Carried over .	..	..	..	1,257,851,000

TABLE 5.—*Dr. Krishnan's estimates of Iron-Ore in Keonjhar State*—concld.

Locality of deposit.	Area in hundredths of a square mile.	Thick-ness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	1,257,851,000
East and south of Konupus . float .	12·5	6	30	697,000
Burda (2 areas) float . . .	12	5	40	418,000
37. Maha Parbat	4	40	15	2,974,000
„ „ float . . .	4	5	40	139,000
38. Godabudini (in shale) . . .	4	25	25	1,115,000
West of Bardi : float . . .	6	5	40	209,000
39. North of Khajurdi Pahar (2 areas) .	2 5	25	15	1,162,000
40. Badamgarh Pahar	16	75	12	27 878,000
41. Between Badamgarh Pahar and Balia Pahar (2 areas)	8·5	40	12	7,809,000
42. Balia Pahar	24	100	12	55 757,000
43. Between Balia Pahar and Malangatoli	4	50	12	4,646,000
44. North of Mitihurda (3 areas) . .	13	50	12	15,101,000
„ float . .	6	6	35	287,000
45. West of Pipokri	27	75	12	47,045,000
46. South of Pipokri (2 areas). . .	12 5	50	12	14,520,000
47. Diring Buru	6	50	15	5,576,000
48. South of Diring Buru (2 areas) . .	10·5	40	12	9,757,000
49. Ranga Parbat	6	75	12	10,454,000
50. Churisai and Loiaboga . . .	6	25	15	2,788,000
„ „ „ float . .	8	5	40	279,000
51. South of Mitihurda	11	50	12	12,778,000
52. Gurda	4·5	37 5	12	3,920,000
TOTAL .	..	..	..	1,483,250,000

Bonai State.

TABLE 6.—*Estimates of Iron-Ore in Bonai State.*

Ore-body.	Area in square feet.	Thick-ness in feet.	Cubic feet per ton	Quantity in tons.
1. Singhbhum-Keonjhar boundary to Samaj *nadi* gorge.	9,504,000	100	12	79,200,000
2. Samaj *nadi* gorge to B. H. Q. break (about three miles).	9,504,000	100	12	79,200,000
Carried over .	..	..	..	158,400,000

TABLE 6.—*Estimates of Iron-Ore in Bonai State*—contd.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	158,400,000
3. B. M. Q. break to path north of Samlaibar Pahar.	6,336,000	100	12	52,800,000
4. Samlaibar Pahar 1½ miles. . .	3,168,000	100	12	26,400,000
5. Bhehikhani Pahar	1,584,000	50	12	6,600,000
6. Dandrahar Pahar (*a*) . . .	9,504,000	100	12	79,200,000
„ (*b*) . . .	1,056,000	200	10	21,120,000
7. Kandadhar Pahar, north of Rontha .	792,000	30	12	1,980,000
8. Chellatoka Pahar	2,112,000	50	12	8,800,000
Between Chellatoka Pahar and Kumritar Pahar.	1,056,000	20	12	1,760,000
Between Chellotoka Pahar and Kumritar Pahar, debris.	24,000,000	5	30	4,000,000
9. Kumritar Pahar	5,280,000	50	12	22,000,000
North of Kumritar Pahar. . .	3,960,000	50	12	16,500,000
North-west of Kumritar Pahar . .	2,376,000	40	12	7,920,000
Debris, north of Kumritar Pahar .	66,000,000	5	30	11,000,000
10. Saraikela-Rontha path to Raisua-Lusi path.	8,448,000	40	12	28,160,000
11. Raisua-Lusi path to Jhubka-Dinakora path.	9,088,000	40	12	30,293,000
12. South of Malangtoli . . .	7,920,000	50	12	33,000,000
13. Ungarpora Pahar, west of Raikela .	2,640,000	50	12	11,000,000
14. North of Rengarbera, mainly debris .	6,316,000	5	30	1,053,000
South of Rengarbera, mainly debris .	1,500,000	10	30	500,000
East of Rengarbera, mainly debris .	1,500,000	10	30	500,000
Solid in above patches . . .			say	800,000
15. North-west of Kasira . . .	1,056,000	20	12	1,760,000
„ „ debris . . .	12,000,000	5	30	2,000,000
16. South-west of Kasira . . .	2,112,000	20	12	3,520,000
17. West of Koira, mainly debris . .	15,840,000	5	30	2,640,000
18. South of Kalmang	1,500,000	36	12	4,500,000
„ „ debris. . . .			say	1,000,000
19. East of Mankarnacha Peak . .	7,200,000	50	12	30,000,000
20. West of Badamgarh Pahar . .	2,112,000	40	12	7,040,000
Carried over .	..	..	..	576,246,000

TABLE 6.—*Estimates of Iron-Ore in Bonai State*—concld.

Ore-body.	Area in square feet.	Thickness in feet.	Cubic feet per ton.	Quantity in tons.
Brought forward .	..	..	..	576,246,000
38. South of Godabudini	1,980,000	20	12	3,300,000
South-west of Bardi, debris . .	3,600,000	5	30	600,000
39. North-west of Kojordi, debris . .	6,000,000	5	30	1,000,000
40. Badamgarh Pahar	5,280,000	50	12	22,000,000
41. Bonai-Keonjhar boundary ridge between Badamgarh Pahar and Balia Pahar.	3,168,000	30	12	7,920,000
42. Balia Pahar	4,752,000	40	12	15,840,000
43. Between Balia Pahar and Malangtoli .	2,400,000	40	12	8,000,000
44. North of Mitihurda	3,960,000	40	12	13,200,000
TOTAL .	..	..	..	648,106,000

CHAPTER IV.

DESCRIPTION OF THE ORE-BODIES.

The numerous ore-bodies that occur in the area under report are briefly described in the following pages, and the descriptions have been kept as far as possible in the order in which they occur in the tables of estimates of ore on pages 250 to 260.

Singhbhum District.

Noamundi ore-bodies.

The Noamundi ore-bodies all occur in a number of low-lying hills close to the village of Noamundi (22° 09′ : 85° 28′), and for purposes of estimation they have been put into nine groups, which have been taken up by the Tata Iron and Steel Co., Ltd. Four of the ore-bodies continue over the boundary into the Keonjhar State. The following are the nine groups, and they are generally named after a prominent hill in which the ore occurs :—

1. Kotamati Buru.
2. Pachri Buru.
3. Bond Buru.
4. Lagirda Buru.
5. Bai Buru.
6. Hatu Gutu.
7. Chariapat Buru.
8. Maha Buru.
9. Hill 1,750 feet (Baljori).

The first six of these ore-bodies occur in four main ridges which run roughly north and south from the Singbhum-Keonjhar boundary, south-east of Noamundi. It appears that the rocks forming these four ridges are separated from each other by three main faults running along the valleys which separate the ridges. The rocks forming the ridges are generally banded hematite-quartzite and shale, and the hematite ore-bodies, which may be a replacement of either of these rocks. The rocks have a general dip to the west or north-west, but the area is much broken up by faults, and local folding is common. During the prospecting and quarrying work carried out by the Tata Iron and Steel Co., Ltd., at their Noamundi mine area, a number of smaller faults have been revealed, and it is probable that when the other ridges are opened up, similar suspected faults will be revealed.

When I first examined the area in February, 1920, the hills were covered with heavy forest, soil and debris, and practically no prospecting work had been carried out. The Kotamati Buru and the Pachri Buru ridges were soon recognised as the largest and richest of the Noamundi ore-bodies.

The deposits are fairly low-lying, and conditions are favourable for easy working. A siding of the Bengal-Nagpur railway takes off from Noamundi railway station, and runs near Sangramsai round the north foot of the Kotamati ridge, and then runs practically along the west boundary of the ore in this ridge.

1. Kotamati Buru.

The ore-bodies in the Kotamati Buru and the Pachri Buru ridges have been partially opened up by the Tata Iron and Steel Co., Ltd., and constitute what is known as the Noamundi mine. The occurrence of the ore, and the prospecting work that has been carried out by the company in these two ridges has been thoroughly described by Dr. Percival[1] in his paper ' The Iron Ores of Noamundi' .

The Kotamati ridge, which extends for about 2¾ miles north of the Singhbhum-Keonjhar boundary, is divided into a number of peaks, in each of which good ore occurs ; but the northern end of the ridge for about three-quarters of a mile is much lateritised, and of much poorer quality than the ore towards the south end, and in the adjoining Pachri Buru, where the ore is massive or massive laminated hematite of a steel-grey colour. The ore is broken up into several patches owing to faulting, but to the east the boundaries of the ore are fairly well defined, as it forms a fairly steep scarp, below which are shales, often ferruginous in character near the ore. The beds dip generally towards the west, and down the dip slope the boundary of the ore is not so well defined, owing to the slope being largely covered with soil, consolidated ore, laterite and debris. The Kotamati Buru ore-body continues into the Keonjhar State, and near the Singhbhum-Keonjhar boundary down the eastern slopes of the hill the ore can be traced for over one hundred feet before being covered with soil and debris, and on the western slopes ore can be seen almost down to the point where the Ginguda Lor crosses the boundary. The average of nineteen samples collected from the

[1] *Trans. Min. Geol. Inst. Ind.*, XXVI, (1931).

whole of the Kotamati Buru ridge, and assayed by the Tata Iron and Steel Co., Ltd., showed :—

	Per cent.
Iron	63·33
Manganese	trace
Sulphur	0·030
Phosphorus	0·088
Insoluble residue	2·14

Titanium was determined in two samples and gave 0·25 and 0·20 per cent. respectively.

Close to the Singhbhum-Keonjhar boundary at the south end of Pachri Buru, and also at the south end of Kotamati Buru, are small cliffs of excellent massive steel-grey hematite, samples of which have assayed over 69 per cent. of iron.

2. *Pachri Buru.*

The Pachri Buru band of ore extends from the Singhbhum-Keonjhar boundary for about $1\frac{1}{2}$ miles in a northerly direction, and also extends for about a mile south of the boundary into Keonjhar State. Near the boundary the ore-body is about nine hundred feet wide, but it widens out considerably to the north near the site of the village of Kurta (22° 08′ : 85° 30′). The ore dips at from 30 to 50° to the W. N. W. The ore is of extremely good quality, especially towards the south end of the ridge, where it is massive and steel-grey in colour, and often forms small cliffs. On the western slopes are considerable quantities of consolidated ore, which, in the bear caves west of Kurta, is seen to overlie rich hematite. This consolidated ore consists of large rounded and angular lumps of steel-grey hematite cemented together by ferruginous material, and constitutes a valuable iron-ore. Similar consolidated ore is also abundant in the upper reaches of the Ginguda Lor, between Kotamati and Pachri Burus, where in places it is over thirty feet thick; some of the fragments are as much as eighteen inches across. The average of assays of eight samples collected and assayed by the Tata Iron and Steel Co., Ltd., is—

	Per cent.
Iron	63·94
Manganese	trace
Sulphur	0·024
Phosphorus	0·072
Insoluble residue	2·49

Four of the above samples were tested for titanium, but only showed a trace.

3. *Bond Buru.*

At the north end of the Pachri Buru ridge are two small rises which contain iron-ore bodies. As is the case with the ore at the north end of the Kotamati ridge, the ore in these two rises is very lateritised, and of much poorer quality than the ore to the south in the Pachri Buru ridge. The ore is generally of the porous laminated type of good quality, having a somewhat shaly appearance, and is much lateritised in both hills; but the ore in the south rise is more massive and of better quality than that in the north. The dip of the rocks is generally westerly. There is some consolidated ore at the south end of the rises. The average analysis of three samples collected and assayed by the Tata Iron and Steel Co., Ltd., gave—

	Per cent.
Iron	64·10
Manganese	trace
Sulphur	0·022
Phosphorus	0·032
Titanium	trace
Insoluble residue	3·08

4. *Lagirda Buru.*

5. *Bai Buru.*

6. *Hatu Gutu.*

These three ore-bodies occur on the ridge to the west of the Pachri Buru ridge. Hatu Gutu is at the north end of the ridge, and is situated just to the south of the village of Noamundi, and is separated from the other two bodies by the valley of the Salkia Lor. Lagirda Buru is on the boundary, and most of the ore-body occurs on the Keonjhar side.

Hatu Gutu is largely covered with soil, hematite and laterite debris, but on all the slopes banded hematite-quartzite is seen *in situ*. Hematite of the porous laminated type is seen in places near the top of the hill, and also down the southern slopes. Like the northern part of the Kotamati and Pachri Buru ridges, this ore-body at the northern part of the ridge, seems of inferior grade to the ore occurring in Bai Buru and Lagirda Buru on the same ridge farther south.

Bai Buru is situated about three-quarters of a mile south of Hatu Gutu. The lower slopes of the hill are banded hematite-quartzite dipping about 40° to the north-west, but the slopes are largely covered with good hematite debris. At the top of the hill is extremely good steel-grey hematite *in situ,* and in the low ground south of the hill is some consolidated hematite debris.

There is a small exposure of shaly-looking porous hematite in the Salkia Lor, about half a mile north-west of Bai Buru. Its extent is doubtful, as the surrounding ground is covered.

The northern slopes of Lagirda Buru, which is just south-west of Bai Buru, are of porous laminated shaly-looking hematite, much lateritised and covered with soil and debris. It extends across the boundary into Keonjhar State. The average analysis of samples collected and assayed by the Tata Iron and Steel Co., Ltd., gave :—

	Hatu Gutu. 2 samples.	Bai Buru. 10 samples.	Lagirda Buru. 2 samples.
	Per cent.	Per cent.	Per cent.
Iron	64·80	64·92	64·80
Manganese	trace	trace	trace
Sulphur . . .	0·022	0·030	0·033
Phosphorus . . .	0·065	0·080	0·081
Titanium	trace	trace	trace
Insoluble residue . .	1·68	2·69	2·38

7. *Charipat Buru.*

Charipat Buru is situated just over a mile south-west of Noamundi village. The ore in this hill is generally of the porous shaly-looking type, and is often very lateritised, but at the top of the hill some good solid laminated ore occurs, and extends over the boundary into Keonjhar State. Banded hematite-quartzite dipping about 20° to the west is seen on both the east and west lower slopes, and towards the south near the top of the hill, the ore seems to pass laterally into the quartzite. The hill is largely covered with soil, laterite and debris, and in places it has a hollow sounding ring when

walked on. An average analysis of six samples collected and assayed by the Tata Iron and Steel Co., Ltd., showed :—

	Per cent.
Iron	63·85
Manganese	trace
Sulphur	0·024
Phosphorus	0·088
Insoluble residue	2·56

8. *Maha Buru.*

Just to the west of Noamundi are two small hills known as Maha Buru, which contain iron-ore. The ore which caps these two small hills is quite different to most of the ore in the iron-ore area, and was referred to by me in 1920 as a coarse sandstone or fine conglomerate, and should probably be referred to the breccia type of ore. It consists of pebbles which are usually well-rounded, and seldom over a quarter of an inch in diameter, cemented together by hematite. The pebbles are mainly hematite, but pebbles of quartz, shaly material and jasper occur, with an occasional pebble of banded hematite-quartzite. The amount of ore in these two bodies is not large, and it is often lateritised at the surface. The ore does not appear to be of nearly such good quality as the ore in the other Noamundi ore-bodies, but assays show the iron content to be much the same, but the insoluble matter is much higher. Assay of a sample collected by me and assayed in the Geological Survey Laboratory showed 64 per cent. of iron, whilst a sample collected and assayed by the Tata Iron and Steel Co., Ltd., gave :—

	Per cent.
Iron	63·05
Manganese	trace
Sulphur	0·028
Phosphorus	0·047
Insoluble residue	7·70

9. *Hill 1,750 feet (Baljori).*

This ore-body is situated about a mile to the N. N. W. of Noamundi. The ore is of the conglomeratic or breccia type, and seems to be fairly rich in parts. No prospecting pits have been opened up, and as the area is rather covered, the amount of ore is

doubtful, but it does not seem to be very large. A sample collected by me from this body, and assayed in the Geological Survey Laboratory gave 64·4 per cent. of iron, whilst a sample collected and assayed by the Tata Iron and Steel Co., Ltd., gave:—

	Per cent.
Iron	63·40
Manganese	trace
Sulphur	0·057
Phosphorus	0·023
Insoluble residue	6·60

10. Notu Buru.

11. Pansira Buru.

12. Banalata Buru.

The Pansira range of hills is about twenty-five miles in length, and runs in a north-east to south-west direction about ten miles to the east of the village of Salai (22° 20′ : 85° 20′). The ridge rises some 1,400 feet above the surrounding plain country, and contains three main bodies of high grade iron-ore, which occur along the top of the ridge, but Pansira Buru is the only one that has been opened up. There are other patches of hematite on the ridge, but they are small and unimportant. The hills consist mainly of banded hematite-quartzite with shale on the lower slopes. The rocks strike north-east to south-west and generally have a variable steep dip to the north-west.

Pansira Buru was the first of the ore-bodies to be opened up in the Bihar and Orissa iron-ore area, and quarrying was commenced by the Bengal Iron and Steel Co., Ltd., now the Bengal Iron Co., Ltd., in 1910. There is a body of rich hematite which can be traced for about 2,600 feet in length, but it has been largely lateritised at the surface. A tunnel put into the western side of the hill went through 82 feet of fairly hard high-grade hematite, and was followed by some 120 feet of soft blue powdery hematite. A second tunnel put in at the same level, but farther to the south, showed similar features. Another tunnel put in at a higher level showed about the same thickness of hard and soft ore, and then went into banded hematite-quartzite. Thin bands, varying from half an inch or less up to nearly three feet, of clayey or sandy material occasionally occurs in the middle of the hematite. These bands are often white or very pale-coloured, and have the same strike and dip as the

hematite. Both the rocks and the ore often show small local folds. The average analysis of the ore given me by the Bengal Iron Co, Ltd., is :—

	Per cent.
Iron	64·00
Silica	3·00
Manganese	0·06
Phosphorus	0·05

My estimate for this ore-body made in 1920 was nearly 10,000,000 tons of ore, of which some 25 to 30 per cent. seems to be solid ore, and the remainder of powdery hematite and laterite.

Notu Buru (also known as Lotu Buru) is situated about two miles to the north-east of the Pansira ore-body. It is similar in appearance to that body, but it has not yet been opened up. The ore can be traced for about 1,300 feet along the ridge, and for about 240 feet across. It is generally a good grey hematite, solid in parts, but in other parts it is porous and thinly-bedded, which gives it a rather shaly appearance. In parts it is lateritised.

The Banalata ore-body is situated about ten miles along the top of the ridge to the south-west of the Pansira body. It has not yet been opened up, but it appears to be similar in occurrence and in general character to the Pansira ore-body, and can be traced for nearly 3,000 feet along the ridge, and for some 250 feet across, but the ground is largely covered. Good hematite debris occurs on the lower west slopes of the hill. The ore is associated with banded hematite-quartzite which dips 70° to the north-west.

13. Buda Buru.
14. Bogordui Buru.

These two ridges occur in the Ankua reserved forest area, and are situated to the south of the village of Chiria (22° 18′ : 85° 17′). They cover a large area, and are made up of a number of hills covered with forest, soil, laterite, etc., and is generally such rough and covered country that it is impossible to get more than a very rough idea of quantities of ore in these areas, without a systematic cutting of lines through the forests, making a large number of borings and pits, and a survey of the area on a fairly large scale. My estimates of about 174,000,000 tons of ore must therefore be considered in the nature of a shrewd guess, after I had geologically explored the area with the aid of the four-inch to the mile forest maps, making

occasional measurements, and taking advantage of information to be gained from the little quarrying and tunnelling that has been carried out at the northern end of the mass of hills. Buda Buru, the highest point of the hills, rises some 1,700 feet above the adjoining valleys. The area has been taken up by the Bengal Iron Co., Ltd.

The Buda Buru ridge is fairly flat-topped and is some two miles in length. It runs roughly N. N. E. to S. S. W., and has two main rises or peaks known as Buda Buru and Balchindigi Buru. To the north-east the ridge falls away but continues for over a mile and is known as Leda Buru. To the S. S. W. the ridge also falls away from Balchindigi Buru for about two miles. A small spur known as Jopano Buru connects the Buda Buru and the Bogordui ridges. Another small spur runs out to the north-west of Buda Buru, and is known as Ajita Buru. This and the slopes towards Leda Buru are the only parts where tunnelling and quarrying operations have been carried out. Ajita Buru contains a small body of good iron-ore that is separated from the Buda Buru mass by banded hematite-quartzite dipping 40° to the north-west. The ore at the surface is rather lateritised, but is generally porous and rather shaly-looking in character, although some of the powdery type is encountered in some of the quarry faces.

Two tunnels were put into the side of this hill, at about the 2000-foot level; the first of these went into about 100 feet of good hematite, rather shaly and sometimes powdery in character, and was stopped. The second, which was put in at right angles to the strike of the beds, went into nearly 200 feet of similar ore before the tunnel was stopped. About half way along this second tunnel, two bands eight and twelve inches wide and several thinner ones, consisting of white and reddish clayey material, were encountered. These bands have the same dip as the ore which is about 50° in a north-westerly direction, but is somewhat flatter near the entrance of the tunnel. It appears that about half of the ore in this tunnel is of the blue powdery type. Some of the bands of the shaly ore in these tunnels show marked quantities of octahedral crystals of martite. The west side of the rise Buda Buru is largely covered, and although at the top and top west slopes much rich solid and laminated shaly-looking ore is seen *in situ*, the ore is often lateritised and covered with soil and debris. Good ore can be traced down the west slopes to the 2,200-foot contour, below which is banded hematite-quartzite dipping to the west, but is much folded and gives

rise to waterfalls in the streams. The low ground between the two rises Buda Buru and Balchindigi Buru is covered, but rich hematite is again seen in the latter rise. On the east side of the ridge, between these two hills, at about the 2,500-foot level, is a cliff of somewhat lateritised hematite, which continues to the north round Jopano Buru. The top of Jopano Buru is of rich porous steel-grey hematite, but the eastern slopes are very covered. The southern slopes of Balchindigi Buru contain quantities of consolidated ore, consisting of fragments of good rich hematite cemented together by ferruginous material. Large quantities of laterite occur on the ridge, and to the south of Balchindigi Buru forms a fairly flat area which is rather marked as it contains practically no trees, and the vegetation which occurs is a pale-coloured grass. This flat area is also marked by the hollow ringing sound which is produced when walked on. Leda Buru at the north-easterly end of the ridge has rich steel-grey hematite, but the cliffs north of the hill are of banded hematite-quartzite, which is also seen on the eastern slopes.

The Bogordui Buru ridge is about a mile in length, and is situated just to the east of the Buda Buru ridge. Its southern and eastern slopes are of rich hematite, and at about the 2,200-foot level on the eastern slopes is a marked cliff of rich, rather porous steel-grey hematite which is lateritised in places, and runs along the hill for about half a mile before being covered by lateritic material. The lower eastern slopes of the ridge are banded hematite-quartzite dipping to the north-west, but at the top of the hill is a band of shale, the extent of which is hidden by lateritic material. This lateritic material contains large quantities of fragments of solid steel-grey hematite.

15. Marang Ponga.

This ore-body is situated about two miles north of the village of Marang Ponga (22° 14′ : 85° 14′), and exposures of rich hematite are seen at and near the top of a ridge running slightly east of north and south, for a distance of just over a mile. The lower slopes of the ridge are of purple and red ferruginous shale, which is overlain by banded hematite-quartzite, which is well exposed at the south end of the ridge. Good hematite is seen running in a northerly direction from the triangulation station at the south end of the ridge, for over a mile and a quarter along the top, and also along a small spur which runs out towards the N. N. W. for about a

quarter of a mile. The hematite in parts is lateritised, especially towards the north, but good solid steel-grey hematite striking nearly north and south and dipping 50 to 60° to the west, occurs near the centre and top, and again in a small rise farther north along the ridge. The hematite in parts is of the porous shaly type, and this often gets lateritised and covered. Near the centre of the ridge where the solid steel-grey ore occurs, the hematite beds measure about five hundred feet across the strike.

At the south end of the ridge, the hematite band gets thinner and dies out at the south-east edge, and seems to gradually pass into the banded hematite-quartzite, which has the same strike and dip as the hematite, but about half way down the southern slopes of the ridge is a patch of good hematite, but it seems to be of small extent.

A sample of the ore collected by me from across the strike near the centre of the ridge where the solid steel-grey ore occurs, and assayed in the Geological Survey Laboratory, gave nearly 70 per cent. of iron, whilst a second sample collected from the whole of the ore-body gave 64·05 per cent. of iron.

16. Dirisium Buru.

17. Hokolata Buru.

These two ore-bodies which are much lateritised, occur just over two miles to the south-east of the village of Marang Ponga (22° 14′ : 85° 14′), and occupy the tops of two fairly high hills which have marked steep scarps to the south and south-east. I have estimated these as two separate ore-bodies, although there is evidence of ore between the two hills, and this may be connected, but the ground between the hills is very covered, and prospecting pits are necessary to prove this connection. The lower slopes of the hills consist of alternations of purple and ferruginous shales with banded hematite-quartzites, striking north-east to south-west and dipping at a fairly high angle to the north-west, Cliffs of good ore, fifty to nearly one hundred feet in height, can be seen on the south and west slopes of Dirisium Buru, and on the south-east and west slopes of Hokolata Buru, but these are usually rather lateritised. At the top of each of the hills rich solid steel-grey hematite occurs, which in Dirisium Buru can be traced for a considerable distance across the strike, but both hills slope off gradually in a north and north-westerly direction, and the ore gradually becomes covered with soil and

debris. Considerable quantities of hematite debris occurs on the north-west and easterly slopes of Dirisium Buru, and also on the north-west slopes of Hokolata Buru, and in places this has been cemented together by ferruginous material to form a consolidated ore.

The average analysis of six samples collected from these ore-bodies, and analysed by the Tata Iron and Steel Co., Ltd., is shown on page 238, and runs 62·95 per cent. of iron.

18. Jalamjal Buru.

This is a small ore-body which occurs at the top of a low hill on the east side of the Karo river, about thirteen miles west of Jamda (22° 10′ : 85° 26′). The ore-body runs in a north to south direction for nearly half a mile, and it is about 150 to 200 feet wide. The ore is a porous rather shaly-looking laminated hematite, rather lateritised at the surface, and is largely covered with forest and soil, so that little information can be obtained without pitting, as to the depth to which the ore extends. At the south end of the hill, some manganese-ore was noted, and on the western slopes of the hill, lateritic manganese-ore occurs, but prospecting pits have failed to reveal any rich body of manganese-ore.

19. Chatua Buru.
20. Jarida Buru, (south area).
21. East of Idri Buru.
22. East of Jarida Buru.
23. Jarida Buru.

These ore-bodies occur in the hills that lie between Pechahatu (22° 16′ : 85° 22′) and Lipunga (22° 15′ : 85° 26′), and with the exception of the Chatua Buru ore-body occur on a northern extension of the Gua range. The Chatua Buru ore-body lies about three miles to the east of the main range. This section of the main range, for convenience of estimation has been divided into four sections, although ore is almost continuous along its length of about three miles. The bodies seem to be more indefinite than most of the ore-bodies in Singhbhum, as replacement of the original banded hematite-quartzite seems to be more imperfect, and rich ores often seem to pass laterally into the quartzite, and after a short distance, back

again into ore. Patches of the barren unaltered quartzite are found frequently in the ore-bodies. The bodies occur in very rough rugged country, covered with heavy forest, the hills being very steep in parts, and the rock and ore often being covered with a thick layer of soil and debris. Most of the ore occurs on or near the tops of the hills, which rise some 1,000 to 1,300 feet above the plains. No prospecting pits have been put down, and no quarrying has been done, but the ore seen is usually of fair quality, although little of the massive steel-grey type is seen, the ore being generally of the laminated type, at times porous and shaly in character, and much of the ore is lateritised at the surface. The slopes of the hills contain large quantities of hematite debris, and this is especially noticeable on the western slopes. A sample of ore collected by me from the ore-bodies on the main range, and analysed in the Geological Survey Laboratory, gave 64 per cent. of iron, and this is much the same as the Tata Iron and Steel Co., Ltd., obtained as the average analysis shown and referred to on page 238, of eighteen samples collected and analysed by them.

The Chatua Buru ore-body occurs at the northern end of the Chatua Buru ridge, which runs in a north-east to south-west direction, and the ore is exposed on the top north-western slopes of the hill. The hill is heavily covered with forest and soil, and comparatively little ore can be seen *in situ.* The ore is porous, laminated, and rather shaly in character, and is usually much lateritised. Rich hematite debris occurs down the western slopes of the hill. No prospecting pits have been opened up on this ore-body. Analysis of a sample of the ore collected by me, and analysed in the Geological Survey Laboratory, gave 64·42 per cent. of iron.

Jarida Buru (south area) ore-body occurs on a continuation to the north-east of the Gua main iron-ore range, and this rise forms part of what is locally known as Raja Buru. The ore-body extends for a distance of about 2,500 feet from the forest line which marks the northern boundary of the area taken up by the Indian Iron and Steel Co., Ltd., and stretches in a north-easterly direction towards Jarida Buru. The ore seems to pass laterally into banded hematite-quartzite along the strike in the direction of Jarida Buru, although, owing to the covered nature of the ground, the actual passage of one to the other is not seen, and after a short distance the quartzite again passes into ore. A small patch of ore occurs between this body and the Jarida ore-body to the north, and may be connected to the Jarida body, but the ground is too covered to determine this.

The ore is laminated, rather porous, and shaly in appearance, and is often lateritised at the surface.

The ore-body east of Idri Buru occurs in a small rise which is known locally as Richi Buru, and the ore can be traced for about half a mile along the ridge, and is separated from ore-body No. 22 by a small stretch of banded hematite-quartzite. The ore is of fair quality, but towards the north end of the body, it gets more porous and lateritised. The ore in this body does not seem to be of such good quality as that in the ore-bodies farther to the south.

The ore-body east of Jarida Buru occurs on the top of the ridge known locally as Landrup Buru. It is largely covered with soil and debris, but rich hematite often lateritised is occasionally seen. Some irregular patches of banded hematite-quartzite occur in the ore-body, and it seems that replacement in this ridge has been very irregular, so that estimates made of quantities of ore in this body are not very reliable. On the lower western slopes of the ridge is a cliff, about 100 feet high, of hematite of good quality, separated from the main ore-body by banded hematite-quartzite.

Good hematite is seen *in situ* at the top of Jarida Buru, but its extent is somewhat doubtful, as the ground is very covered. The northern slopes of the ridge are banded hematite-quartzite, but some conglomerate occurs on the lower eastern slopes, and towards the south end of the hill the rocks are very folded. The western slopes are largely covered with soil, amongst which is considerable quantities of rich hematite debris. At the north end of the ridge is a small body of rich hematite which is separated from the main body by banded hematite-quartzite. The ore is generally porous laminated hematite, in parts partly lateritised.

24. Durbar Buru to north boundary.

27. Duarguia Buru.

The ore-bodies in these two sections occur at the top of the main iron-ore range just west of the village of Gua (22° 13′ : 85° 23′), and have been opened up to a certain extent by the quarrying operations of the Indian Iron and Steel Co., Ltd. No borings have been put down, but before quarrying operations were commenced, a number of trenches and prospecting pits were made.

From the south end of Durbar Buru, along the range to the northern boundary of the Indian Iron and Steel Company's property is a distance of about 3½ miles, and good hematite occurs along the

top for almost the whole distance. The range runs nearly north-east to south-west, and the various rises on it are known as Raja Buru, Raijori Buru (One-Tree Hill), Bonamuli Buru, Honjurdiri Buru, Bai Buru and Durbar Buru. These rises are 1,000 to 1,300 feet above the plains of Gua. Prospecting and quarrying operations have been confined mainly to One-Tree Hill, Bonamuli Buru and Honjurdiri Buru, which seem to contain some of the richest ore in this part of the range.

At the northern end of the property is part of Raja Buru, and the ore at the top of this hill is similar in character and a continuation of the ore-body described under No. 20, Jarida Buru (south area). The ore seems to get richer and less lateritised towards the south.

Rich hematite occurs on the top and down the slopes of One-Tree Hill, and this is especially noticed on the western slopes where ore *in situ* can be traced some three hundred feet below the top. On the east side of Bonamuli Buru and One-Tree Hill, thin-bedded powdery hematite occurs. A certain amount of this powder ore was observed before quarrying operations had commenced, but with the removal of the outer hard crust of partly lateritised hematite, considerable quantities of this soft ore is seen. Thin bands of clayey and siliceous material occur, running parallel to the bedding in this soft blue ore. Below the ore is banded hematite-quartzite striking north-east to south-west, and dipping 70° to the north-west. On the east side of the range, banded hematite-quartzite occurs overlying the buff, purple and whitish shales which are seen in the Gua plain. The rocks are very much bent about, and replacement of the banded hematite-quartzite has been irregular. At several points along the range there are short lengths of cliffs of rich hematite from 50 to 70 feet high.

The ore in Bai Buru seems to be rich steel-grey hematite, laminated in parts, but generally of good quality; towards the south-west this ore seems to pass laterally into banded hematite-quartzite, which again further to the south-west passes laterally into the hematite which forms the Durbar Buru ore-body. The ore on Durbar Buru does not seem to be of such good quality as that to the north-east, and seems to be much intermixed with banded hematite-quartzite. In the Rai-kichri Loi on the lower western slopes of Durbar Buru, is some blue powder hematite, but the slopes are too covered to determine its extent.

South-west of Durbar Buru is about half a mile of banded hematite-quartzite, which seems to pass laterally towards the south-west into the hematite of Duarguia Buru. A second ore-body occurs on the south-west slopes of Duarguia Buru, and is separated from the first by banded hematite-quartzite. The hematite and the quartzite have a steep dip to the north-west. The ore generally does not seem to be of such good quality as in the hills where quarrying is being carried on.

25. Baya Buru.

Baya Buru is a conical shaped hill, 1½ miles south-west of Gua. The lower slopes of the hill consist of white and purplish coloured shales, but towards the top is banded hematite-quartzite striking north-east to south-west and dipping 70° to the north-west. The slopes of the hill are largely covered, but at the top is good laminated, somewhat porous hematite associated with some of the massive steel-grey type, the whole being lateritised to some extent. The quantity of ore on the hill is comparatively small, about a million tons, but owing to the steep slopes of the hill, will be rather difficult to work and get away.

26. Jiling Buru.

Jiling Buru is a comparatively low hill situated close to the west bank of the Karo river, just over a mile to the south of the village of Gua, and about a mile to the east of the main iron-ore range. The ore-body in this hill is being opened up by the Indian Iron and Steel Co., Ltd. The ore is of quite a different type from that of most of the ore in the area, in that it is a hematite breccia consisting mainly of fragments of steel-grey hematite cemented together generally by hematite. Occasional fragments of jasper and banded hematite-quartzite occur in it, and at times these form the predominating material in the rock, and when this is the case, the material is useless as an iron-ore. The richest material seems to come from the south-west slopes near the top of the hill. The rock is massive, very hard and well-bedded, but the bedding can be confused with a series of very well defined joints in the rock. The ore is generally of good quality, the better parts averaging about 65 per cent. of iron, but care has to be exercised in the quarrying and despatching to avoid the material with the siliceous fragments. The beds are

rather bent about, but seem to be generally folded into an anticline, but the area is much covered, and on the west side of the hill is much lateritised. On the east side of the hill the ore-beds dip some 40 to 60° to the east or E. N. E., and on the west side of the hill they dip a similar amount to the south-west. The ore-beds which are well exposed at the top of the hill, which is some four hundred feet above the river, seem to be a band in the shales, and are overlain by a thin band of cherty material, which is seen on both the east and west sides of the hill, and is overlain in turn by shales which are generally of a white or pale-grey colour. The cherty band is possibly due to silicification of the shales.

Before the forest and soil had been cleared from the surface, and before quarrying operations had been commenced to any extent, I took twenty feet as the thickness of the ore, but later work has shown that this figure is much too small, and that my estimate of 2,000,000 tons of ore should be very largely increased.

28. Hill 10 to Ajiti Buru.

29. Body east of ore-body 28.

These two ore-bodies occur in the northern part of the main iron-ore range, and are situated about 1½ miles to the north-west of the village of Baraiburu (22° 09′ : 85° 22′), and ore occurs along the top for practically the whole length of about two and a quarter miles. The ore-body and ore is similar to that in the main Gua range described under No. 24 on page 274. At the top of the ridge there is good solid steel-grey hematite *in situ*, but most of the ore is laminated and rather porous. On the north-west edge of the ridge there is a low cliff about fifteen feet high of rich hematite, but some soft blue powder ore also occurs on this side.

On the lower south-eastern slopes of Hill 10 is a second ore-body No. 29, which is a continuation of the Tatiba ore-body No. 33, and it is well exposed along the forest boundary line, and in the Darkada Gara. The body is indicated by a cliff of rather lateritised shaly-looking and earthy hematite, and is separated from the upper ore-body by banded hematite-quartzite, which is jaspery in character, and dips 70° to the north-west, the hematite having a similar dip.

30. Jiripai Buru.

This is a continuation to the south of the ore-bodies described under Nos. 28 and 29, and lies some five miles to the west of

Baraiburu. It was estimated separately on page 251, because the area was taken up by the Bengal Iron Co., Ltd., whilst the areas to the north and to the south were taken up by other companies. The ridge is largely covered with soil and debris, and is very similar to that described under Nos. 28 and 29. The upper body of ore is separated from the ore-body to the north by banded hematite-quartzite, but the occurrence and general character of the ore is similar. Good solid steel-grey hematite is seen on the top of the ridge, and also on the main road near the top south end of the ridge near the Bilaichopi pass, but laminated and porous hematite also occurs. The highest point of Jiripai Buru is nearly eight hundred feet above the road at the pass, and is some 1,300 feet above the low ground near Baraiburu. Some low cliffs of rich hematite occur on both the east and west slopes of the ridge.

The lower band of ore is much lateritised, and in parts it is manganiferous. Some prospecting pits have been put down on Pachripi Buru and other eastern lower slopes, and good hematite and manganese-ore occurs *in situ*, but most of the manganese-ore is of inferior quality, and requires a lot of trimming and hand-picking to get any quantity of first grade ore. The iron-ore is generally laminated, often lateritised at the surface, and largely covered. Considerable quantities of hematite debris are found on the slopes of the ridge, and in places this has been cemented together by ferruginous material to form a hard, rich consolidated ore.

31. *Sasangda.*

This series of hills is a continuation to the south of the main iron-ore range at Gua, and generally marks the boundary between the Singhbhum district and the Keonjhar State. The area on the Singbhum side of the boundary has been applied for by the Tata Iron and Steel Co., Ltd., and that on the Keonjhar side by Messrs. Bird and Co., Ltd.

The portion of the range applied for by the Tata Iron and Steel Co., Ltd. is nearly six miles in length, and is of variable width. Good hematite occurs for practically the whole of this length, but the depth to which the ore extends is variable, and figures are little more than a guess as practically no prospecting work has been done, and no borings have been put down. Streams which run down the western side of the range sometimes expose the ore, and from the difference of elevation of these exposures and the ore exposed at the

tops of the hills, there is about four hundred feet. In the Churdia Lor in the northern part of the area hematite can be traced down the stream to a level about four hundred feet below the hills on the side of the stream; in the Maghahatu Gara which runs away from near the centre of the area, hematite occurs well over four hundred feet below the ore exposed in the hilltops near the stream; in the Garahatu Lor which runs away from towards the south end of the property, there is a difference of level of about three hundred feet.

The ore occurs associated with banded hematite-quartzite, which is well exposed on each side of the range, and also on the boundary line near the Katkamua Pass at the south end of Keonjhar (Kiri) Buru, at the south end of the property. The ore and the quartzite at this point strikes N. N. E. and dips about 70° to the W. N. W. In the stream south of Keonjhar Buru, the hematite seems to pass laterally into the quartzite, but no actual junction or passage is seen as the ground is covered. In the centre of the area there is a plain on which the old village of Sasangda (22° 07′ : 85° 18′) was situated, and near this point the rocks seem to have been much folded and disturbed. Soft white shales, similar to those noted at Gua and Noamundi as occurring below the banded hematite-quartzite, are seen in the tank towards the south end of this plain, but the slopes on each side of the range here show banded hematite-quartzite. This shale is evidently brought up by a sharp anticlinal fold.

The main body of ore occurs on the western side of the top of the range, and the ore is generally a massive or laminated, steel-grey hematite, but becomes more porous to the east, until near the eastern edges it is generally porous, laminated with a shaly appearance, and is often much lateritised at the surface

Some magnetite occurs as small octahedral crystals in some of the bands of hematite, and also in the banded hematite-quartzite, and although not large in quantity, is sufficient to affect readings with the magnetic compass. Octahedral crystals of martite also occur, and these and the magnetite crystals seem to be most abundant in the porous ore. Large quantities of hematite debris occur on the slopes of the range, but the amounts are negligible when compared with the tremendous quantity of ore *in situ* on the range.

Rich hematite occurs in the ridge to the south-west of Sitaladi Buru at the north-east end of the property, and the easterly slopes are covered with good hematite debris.

Sasangda Buru and the hills near it at the north end of the property, and to the south-west of Sitaladi Buru are mainly massive steel-grey hematite of excellent quality, but a certain amount of lateritisation has taken place. The upper western slopes of Sasangda Buru are of banded hematite-quartzite dipping at a very high angle to the north-west, and this rock forms steep cliffs and waterfalls in the Rogara Gara.

In the upper reaches of the Maghahatu Gara are some cliffs with a large cave in rich solid steel-grey hematite, but below this is banded hematite-quartzite dipping steeply to the north-west and making an almost impassable barrier which forms a series of waterfalls in the stream. In the stream near the top of the range is laterite which has a laminated or shaly appearance and is evidently covering good hematite.

The width of ore exposed across the range in the hills just north of Keonjhar (Kiri) Buru at the south end of the property is about 1,000 feet, and it is mainly rich massive steel-grey hematite, but east of the Singhbhum-Keonjhar boundary it seems to become more porous and shaly in appearace, and is more lateritised in character.

South of the Katkamua pass (22° 03′ : 85° 16′) to the tri-junction boundary pillar has been taken up by Messrs. Bird and Co., Ltd., who have put down a few prospecting pits. Near the pass replacement of the quartzite has been imperfect, but a short distance farther south good hematite again occurs. The top of the range in this Gandi Buru section narrows down considerably. The small hill south of Keonjhar Buru, between the Lasara Gara gorge and the Katkamua pass is rich massive steel-grey hematite, but the Gandi Buru section from this small hill to the Bonai boundary is very much lateritised. Porous laminated shaly-looking hematite is exposed in places, and much of the laterite looks as if it had resulted from the alteration of this ore.

The eastern slopes of this portion of the range are in the Keonjhar State, and a short description of this side is given under Keonjhar State ore-bodies No. 57 on page 291.

32. Tatiba, upper ore-body.

33. Tatiba, lower ore-body.

These ore-bodies occur in an area to the south-west of Baraiburu, which was prospected by Messrs. Villiers, Ltd., and lies between

the Sasangda area No. 31, the Keonjhar side Sasangda area No. 57, and the Jiripai Buru area No. 30.

The ore-bodies are well exposed in the Uskirangwa Lor, in the Tatiba Gara, and also in the slopes and top of the Sitaladi Buru, and they extend right through the property, which is about a mile in length.

The upper ore-body occurs at the top of the range, in what is known as Sitaladi Buru, and is a continuation in a north-easterly direction of some of the main Sasangda ore. The width of this ore-body is about four hundred feet. Rich solid steel-grey hematite is exposed at the top of the hill, and on the eastern slopes, where it is seen dipping about 50° to 60° to the north-west, but the ore is generally of the laminated type, and is often fairly porous. In places it is much lateritised. The south-easterly slopes are covered with rich hematite debris.

The lower ore-body is a continuation to the north of the lower body No. 57 held by Messrs. Bird and Co., Ltd., in the adjoining Keonjhar State, and described on page 291. It can be traced right through the property, and is well exposed in the Uskida Lor which forms the south boundary of the property, in the Uskirangwa Lor in the centre, and in the Tatiba Gara where it forms a series of small waterfalls, and which forms the northern boundary of the property. It is also exposed on the lower slopes of the range, but hematite and other debris often hide the ore-body. The ore is generally laminated, sometimes porous, and at the surface it is often lateritised. Some blue powdery hematite is seen. The ore-body appears to be some 800 to 1,000 feet in width.

There is possibly another small band of ore between these two ore-bodies, but this is somewhat doubtful, as the ground is very covered.

34. *Silpui area, Jamda.*

A number of prospecting pits were put down in the Silpui area, mainly on Ratandu Buru, just north of Jamda village (22° 10′ : 85° 26′), but few of them went below three or four feet in depth. Ratandu Buru was originally pitted by Messrs. Villiers, Ltd., but was taken over later by the Bengal Iron Co., Ltd. It is doubtful if any solid ore occurs, although a small ridge of hematite at the top of Ratandu Buru may be *in situ*, but a considerable amount of rich hematite debris occurs lying on the surface and the prospecting pits on the hill show that the debris extends to a depth averaging

about three feet, and of the material excavated from the pits, about half is good hematite, and the remainder is gravelly ferruginous material. The hill seems to be mainly purple ferruginous shale, sometimes sandy in character, and dipping variably from 40° to 70° to the north-west, but on the western side of the hill is a band of cherty material. On the eastern side of the hill there is a certain amount of manganiferous matter, but the prospecting pits have failed to reveal any quantity of manganese-ore or any real ore-body. Similar manganiferous material occurs at several points near the village of Jamda. In some of the railway cuttings near Bara Jamda railway station, thin stringers of pyrolusite and other manganese material occurs, and also in the laterite cuttings just south of the bungalow at Jamda, but they seem to be of no economic value. Riari Buru, east of Jamda, and the small hills (Landub Buru and Senda Buru) to the south-east of Jamda seem to be lateritised shale. but they all contain pyrolusite and other manganiferous matter, together with good hematite debris.

Keonjhar State.

I visited practically all the iron-ore bodies in the Keonjhar State, with the exception of those in the isolated Ganda Mardan hills. I did not have an opportunity to make estimates of quantities of ore in the following ore-bodies which occur in the State, but in the tables on pages 251 to 255, I have incorporated the estimates made either by Capt. Teychenné or Dr. Krishnan, both of the Geological Survey, toobtain an idea of the total quantity of ore in the State :—

No. 7. Sidhamat Parbat.
No. 8. Durga Parbat.
No. 13. Jiling Pahar.
No. 15. Kurband area.
No. 26. Kundrupani and Chur Mala.
No. 37. Maha Parbat.
No. 50. Churasai and Loiaboga (Loiboga).
No. 55. Ganda Mardan.

At the time of my early visits to Keonjhar State, the only maps available were the old Bengal Survey sheets on a scale of one inch to a mile, which were made about seventy years ago, and I have only been able to check up a few of the ore-bodies with the assistance of the new maps.

The ore-bodies in Thakurani Hill and in Joda East Hill, appear to be the largest and the richest in the State, but some of the other ore-bodies such as in the area near Kurband, and near Burda, contain large quantities of very massive steel-grey hematite. The ore in the area round Barabil, and the country to the south, occurs in low-lying irregular shaped hills, often rising out of a cultivated alluvial plain, and comparatively little ore is seen *in situ* as the rocks are very lateritised, and the hills are largely covered with hematite and laterite debris.

1. South end of Kotamati Buru.
2. South end of Pachri Buru.
3. Included in Singhbhum No. 7.

The ore in these bodies is a continuation of that described in the Singhbhum iron-ore bodies Nos. 1, 2, 4 and 7 on pages 262 to 266. The Charipat Buru ore-body No. 7 only extends a short distance into the Keonjhar State, but the Kotamati Buru, the Pachri Buru and the Lagirda Buru bodies extend for about a mile in each case to the south of the Singhbhum-Keonjhar boundary. The ore and its occurrence is generally similar to that which occurs at the south end of the corresponding ore-bodies in Singhbhum.

4. Thakurani.

The Thakurani hill-mass consists of three main ridges which rise some 1,300 feet above the plain, and is situated in the northern part of the Keonjhar State, and about twelve miles south-east of Barabil (22° 07′ : 85° 24′). The hill-mass consists of banded hematite-quartzite, with the upper part of each of the ridges occupied by rich hematite. The rocks dip generally to the north-west at high angles, but are much contorted and folded.

The eastern ridge shows good hematite at the top, somewhat lateritised in places, and with a scarp about twenty feet high on the south-east side. The hematite is often covered with consolidated ore. The slopes of the ridge are largely covered with hematite and other debris. At the south end of this ridge the hematite seems to pass laterally into banded hematite-quartzite. The actual passage of one to the other is not seen owing to the covered nature of the ground, but on following along the strike of the hematite beds, after a few yards of covered ground, banded hematite-quartzite occurs.

The western ridge is covered with very heavy forest and soil, but contains a band of hematite which is well seen towards the south end

of the ridge, where near the top western edge some fifty feet of rich hematite is seen, and lower down the slopes just to the east of Dulki (22° 07′ : 85° 25′) is a forty foot cliff of hematite. The east and west slopes of the ridge show banded hematite-quartzite, and some of this rock is seen near the top centre of the ridge.

At the south end of the middle ridge good exposures of rich laminated and massive steel-grey hematite are seen, and rich ore can be traced along the ridge to the north-east for about one and a half miles, and can be traced for over two hundred feet down the east and west slopes before being covered with soil and debris, but lower down the slopes is banded hematite-quartzite. The rocks seem to be bent into an anticlinal fold, but the dip is very variable. The hematite seems to become lateritic at the northern end of the ridge.

5 and 6. Jhargaon.

In the low hillocks stretching from north-west of Jhargaon (22° 03′ : 85° 23′) to south-west of the village is a considerable quantity of hematite and laterite debris, associated with some small ore-bodies, of which the boundaries are rather indefinite owing to the covered nature of the ground. The ore seems to be of fair quality, is rather shaly in appearance, and is generally more or less lateritised at the surface. In the northern part of these hills, there are some exposures of rich laminated hematite, and some manganiferous material occurs. In the small hillock one mile to the west of Jhargaon, iron-ore occurs at the top resting on banded hematite-quartzite. In the lower east slopes underlying the quartzite is some banded limestone, but owing to the covered nature of the ground its extent is doubtful.

7. Sidhamat Parbat.

Sidhamat Parbat is situated just over a mile to the west of Roida (22° 01′ : 85° 23′), and consists of two peaks, the highest of which rises some nine hundred feet above the plain. Some small ore-bodies occur, but the area is very covered and broken up. There is much laterite on the western side of the hill, which is manganiferous in parts.

9 and 21. Joda West.

The area west of Joda (22° 01′ : 85° 26′), which includes Surjat Parbat is largely covered with soil, laterite and debris, and little ore is seen *in situ*. A patch of rusty-looking hematite occurs on the east

slopes of the hill, and both the east and west slopes have good hematite debris, but the top of the hill shows cherty and sandy material. My estimate of 4,000,000 tons is made mainly on the debris material in this area, as it is doubtful if any large quantity of *in situ* ore occurs.

9a. Bhaliathori Pahar.

Bhaliathori Pahar is a flat hillock about two miles south-east of Bhadrasai (22° 03′ : 85° 23′) and is largely soil covered. It is doubtful if any ore occurs *in situ*, but there is a large quantity of good hematite debris, cemented together in parts by lateritic material to form a consolidated ore, and the whole is largely manganiferous. In parts the manganese seems to be the predominating material, but like most of the manganese deposits in this part of Keonjhar State and south Singhbhum, considerable hand-picking is necessary to get much first grade ore. It is possible that hematite occurs *in situ*, but the debris is estimated at about 5,000,000 tons.

10. Joda East.
11. Banspani Pahar.

The ore occurs in the ridge which in the north part is known as Bara Parbat, and in the south end as Banspani Pahar, and is situated to the east of the village of Joda (22° 01′ : 85° 26′). The ridge rises some seven hundred feet above the level of the plain on which Joda is situated, and the western slopes are steeper than the eastern. The area has been taken up by the Tata Iron and Steel Co., Ltd., who have put down two bore-holes and a number of prospecting pits. Bore-hole No. 1 was started in good solid steel-grey hematite, and with the exception of four thin bands of laterite totalling less than four feet in thickness, continued in hard hematite to a depth of ninety-three feet, below which the hematite became powdery in character, and this continued to the bottom of the hole, which was stopped at about 130 feet below the surface. Analyses made by the Tata Iron and Steel Co., Ltd., from material obtained from various parts of the boring show that the solid hematite averages over 68 per cent. iron, whilst the powdery hematite averages about 67·5 per cent. iron. The second bore-hole was put down about 42 feet, of which the top eighteen feet was laterite, and the remainder shale. Hematite occurs at the top slopes and also on the top of the ridge, but a band of shale runs in a roughly north to south direction

through the ridge. The width of this shale band does not seem to be large, but the top is largely covered. On the east slope of the ridge, just to the north of the Kamarjora-Chamakpur path, good massive steel-grey hematite occurs as a cliff (*see* Plate 24) and can be traced down the slope for over a hundred feet, below which the slope is covered, but lower down banded hematite-quartzite occurs. The ore occurs associated with banded hematite-quartzite, which is seen on both east and west slopes of the ridge, and also occurs as irregular patches on the west slopes of Banspani Pahar. The dip of the ore-beds and the quartzite is variable, but seems to be generally at a low angle to the E. S. E. The ore at the north end of the ridge is somewhat lateritised, and some laterite occurs at the top, but from its appearance, most of it seems to be altered hematite. Some parts of this material gives out a hollow ringing sound when walked on.

In the gap between Bara Parbat and Banspani Pahar, hematite is seen *in situ* dipping about 20 in an easterly direction, and rich massive steel-grey hematite occurs at the top of the Banspani hill. The slopes of the hill are largely covered with good hematite debris, but on the south-west top slopes, the dip of the ore is seen to become much steeper, and is as much as 80° in a south-easterly direction, and ore can be seen down the hill side for nearly two hundred feet.

Rich hematite also occurs in the lower ground to the north of the main ridge, and although the ground is partly covered, it is evidently a continuation of the main ore bands. The small hillock to the north of Bara Parbat is mainly banded hematite-quartzite, but some good hematite occurs on the north-western slopes and seems to die out towards the north.

11. East of Joḍā East.

There is a small patch of ore that occurs to the east of the Kala Parbat-Banspani Pahar ridge. The ground is very covered, and the extent of the ore-body is doubtful. Good hematite, lateritised in parts, is seen extending down the east edge of the hill for about thirty feet, before being covered. The west slopes of the hill are largely covered with a red soil, in which is thick hematite and laterite debris. The ore-body is about half a mile in length, and seems to be rather porous and lateritic. At the time of my visit, no prospecting pits had been opened up, but my estimate of 264,000 tons, will, no

doubt, be found to be on the low side when the area is properly prospected.

12. Dal Pahar and north of Kurband.
15. West of Kurband.
23. Between Kurband and Joruri.
24. North-west of Satkutnia Pahar.
28. Satkutnia Pahar.

In the hills on and near the Bonai-Keonjhar boundary, to the west of Kurband (21° 57′ : 85° 24′) and near Gurda (21° 55′ : 85° 23′), some excellent bodies of rich massive steel-grey hematite are well exposed, some of which extend into the Bonai State. In Dal Pahar, and on the north side of Kurband, and in the hills near Joruri, about two miles east of Kurband, there are some good ore-bodies. To the east of the village of Joruri, good ore is seen *in situ* at the tops of the hills, but none of the ore-bodies seem to be very large. To the west of this village there are other ore-bodies, but they seem rather poor in quality, and are much lateritised.

26. Kundrupani and Chur Malda.

In the hills still further to the west of Kurband, between Chur Malda (21° 57′ : 85° 22′) and Kundrupani (21° 58′ : 85° 22′) are several small iron-ore bodies. None of them seem very rich, and they are generally much lateritised.

16 and 27. Guali.

The country round Guali (21° 59′ : 85° 17′) and Burpoda (21° 58′ : 85° 18′) is largely soil covered, but contains several small patches of hematite debris together with some small exposures of hematite *in situ*, in fact, most of the hillocks near these villages show good hematite debris. The low hills forming the Bonai-Keonjhar boundary between Kalmang (21° 57′ : 89° 19′) and Burpoda consist of fairly solid somewhat porous, laminated hematite having rather a shaly appearance, and are partly covered with hematite and laterite debris. The ridge running south-west of Burpoda to Sagasa (21° 57′ : 85° 17′) are similar and show occasional patches of fairly rich ore. The beds are flat, but are largely covered with soil and shaly hematite debris. The low hills between Burpoda and Guali seem to be ferruginous shale covered with soil and hematite debris.

17. One and a half miles north-east of Bhadrasai.

North-east of Bhadrasai (22° 03′ : 85° 23′) are several small hillocks consisting of shale and sandy shale, often ferruginous in character, and largely covered with hematite and laterite debris. The hillock immediately east of the village contains some banded hematite-quartzite, but at the top some hematite occurs *in situ.* All the hillocks are covered with hematite debris, some of which is cemented together by laterite to form consolidated ore. The ore in these hillocks seems to be small in quantity, and not of particularly good quality.

18. Kala Parbat.

Kala Parbat is a somewhat rounded hill which is situated about two miles east of Bhadrasai. The lower slopes of the hill are of white to red sandy shale, but material can be seen on the western slopes which shows a gradual passage from shale to ferruginous shale and eventually into hematite and manganese oxide. The ore is very mixed and the ground is largely covered. Good hematite, porous in character, and often much lateritised occurs at the top east and west slopes but towards the top centre of the hill it becomes covered with soil and hematite and laterite debris. Good rich hematite is again seen *in situ* on the lower south-east slopes, near the road running north-east from Bonaikera (22° 02′ : 85° 25′).

19. Between Raikora and Borita.

Between Raikora (22° 04′ : 85° 25′) and Borita (22° 04′ : 85° 27′) are two small ore-bodies separated by banded hematite-quartzite and ferruginous shale. At the top of the small hillock half a mile east of Raikora, a good rich body of fairly massive hematite occurs, and is well seen at the northern end of the hillock. The ore-body runs along the length of the hillock, and is seen near the top forming a cliff about fifteen feet high, and ore is again seen in the small hillock along the strike of the rocks to the south-east, but the amount of ore is small and is largely covered. This small patch shows some unreplaced patches of the banded hematite-quartzite. In the small hillock half a mile to the south-west is a similar ore-body of about the same extent, but it looks doubtful if the ore goes to any great depth. The ground is very covered with soil and mixed debris,

but the ore-body appears to be about 2,000 feet in length, and about 120 feet wide.

29. Between Gurda and Gonua.

The hills which occur about half way between Gurda (21° 55′ : 85° 23′) and Gonua (21° 55′ : 85° 22′) have an ore-body of good solid steel-grey hematite at the top, and the lower west slopes are covered with rich hematite debris. The ore seems much bent about, but has a general low dip of about 20° to the west. The slopes on the east side of the hill towards Gurda are covered with soil, so the extent of the ore-body is doubtful. The hills to the south and west of Gonua are generally laterite, but the surface is covered with fair quantities of hematite debris.

30, 31, 32 and 33. Areas near Joribar.
34 and 35. Areas near Palsa.
36. South-east of Kunipos and near Boradha.

The hills surrounding the Joribar (21° 56′ : 85° 25′), Palsa (21° 55′ : 85° 25′) and Boradha (Burda) (21° 53′ : 85° 24′) plain contain numerous small bodies of iron-ore. Numerous outcrops of laminated ore are seen, but the area is largely covered with lateritic material and hematite debris, and none of the bodies, seem to be very large. The hills are generally flanked on the east by banded hematite-quartzite, and the western slopes are generally covered with soil and debris. The deposit to the south-west of Palsa is manganiferous.

37. Maha Parbat.

Maha Parbat is situated about two miles to the south-east of the village of Boradha (Burda), and rises about six hundred feet above the low country. On the east side of the hill there is a cliff of banded hematite-quartzite dipping to the north-west, and similar quartzite is seen at the south end of the hill. Hematite occurs at and near the top of the hill, and is generally of a laminated type, often lateritised. Some blue powdery ore is also seen at the top of the hill. The western slopes are covered with soil and hematite debris. The main ore-body seems to be about 1,300 feet in length, and about 300 feet across, and seems richer in the southern part than in the northern part of the hill. There is a considerable quantity of consolidated ore on this hill.

45, 46 and 51. Hills near Mitihurda.
47 and 48. Diring Buru.
49. Ranga Parbat.

The hills along the Bonai-Keonjhar boundary to the east and south-east of Mitihurda (21° 50′ : 85° 20′) contain large quantities of porous laminated hematite, often very much lateritised, but the country is so covered with soil, hematite and other debris, that it is only possible to get a rough idea of the quantities of ore present.

Solid lateritic hematite occurs at the top of Diring Buru, and runs along the ridge towards the north, but farther north passes into banded hematite-quartzite. The south and east slopes of the hill are banded hematite-quartzite.

53. Mankarnacha Peak.

Mankarnacha Peak is situated about two miles north-east of Batgaon (21° 47′ : 85° 13′) and contains a body of good ore at the top of the hill, but it is largely covered with consolidated hematite debris, and is somewhat lateritised in places. The east and west lower slopes of the hill are banded hematite-quartzite.

55. Ganda Mardan.

This is an isolated iron-ore area that I did not have an opportunity to visit, and is situated a short distance to the west of Keonjhargarh (21° 37′ : 85° 35′). Capt. Teychenné who examined the area states that there are four main ore-bodies associated with banded hematite-quartzite, and there is much good hematite debris on the slopes of the hills.

56. North-west of Barabil.

Between Barabil (22° 07′ : 85° 24′) and Uliburu (22° 08′ : 85° 23′) are some low-lying hills which are largely lateritised, and covered with lateritic and porous hematite debris, but some hematite *in situ* is exposed in the highest point of the hill just south-east of Uliburu. There is probably a continuous band of ore running through the hills in a north-east to south-west direction, but the ground is too covered to be certain of this. Messrs Bird and Co., Ltd., who have been working the area for iron and manganese-ore have not opened up enough ground yet to get very reliable estimates of ore present. Similar manganiferous material with hematite occurs

in the low hills about a mile south of Barabil. The material occurs in shale, and the ground is generally covered with laterite and thick soil. In the small rise to the south-east of Sundra (22° 06′ : 85° 23′) some good hematite is exposed, but the ground is very lateritised, and at the highest point of the hill, manganiferous-ore is seen, and the soil is of a black colour. The area is being opened up by Messrs. Bird and Co., Ltd., and from the work done it seems to be the most promising of the manganese occurrences in the area.

The ground between Khendra (22° 09′ : 85° 26′) and Bilkundi (22° 08′ : 85° 24′) is largely covered with lateritic material, in which occurs patches of manganese oxide and some lateritised hematite. The surface also has hematite debris scattered over it. The manganese minerals seem to have been deposited by circulating waters that carried iron and manganese in solution. The distribution is extremely irregular, and the manganese-ore is very variable in quality. By hand-picking a certain amount of first grade ore is obtained, but most of the quarried material is second grade manganese-ore, or mixed iron- and manganese-ore.

57. Sasangda (Keonjhar side).

The ore which occurs at the top of the Sasangda range is divided by the Singhbhum-Keonjhar boundary, and that which occurs on the Keonjhar side is similar to that which occurs on the Singhbhum side, although generally it is not so massive in character, but consists of the more porous laminated type, and on the east edge is often very lateritised. The ore is rich hematite, and averages well over 60 per cent. iron. Good ore, lateritised in places, occurs for almost the whole of the five miles from just north-east of Keonjhar (Kiri) Buru (22° 04′ : 85° 16′) to where the boundary turns east near the Limtur Nadi and averages over seven hundred feet in width. South of Kiri Buru and the Katkamua pass to the tri-junction pillar (22° 00′ : 85° 14′) however, the boundary line runs close to the east edge of the range, so that in this section, only a comparatively small quantity of ore occurs on the Keonjhar side. In this section the ore is a very much lateritised, laminated, shaly-looking hematite, but near the tri-junction pillar there is rich massive hematite forming steep cliffs to the east.

Lower down the slopes on the Keonjhar side of the range are two other bands of ore, which towards the north run into Singhbhum, and

have been described under Singhbhum No. 33, the Tatiba lower ore-body. This lower ore-body runs for about three miles south of the Singhbhum boundary and then dies out. It is possibly cut out by a fault, but the ground is too covered by forest, soil and debris to determine this. The ore is well exposed in the gorge north-west of Panposh (22° 06′ : 85° 20′) where it can be traced up the stream for nearly a thousand feet. The gorge which has practically vertical sides is cut through the laminated hematite, and varies in width from about four to twenty-five feet, with an approximate depth of about 150 feet. The beds dip about 40° up the stream, *i.e.*, to the north-west. Hematite occurs in the Jikaria stream at the south end of this ore-body, but it has become quite a thin band, and seems to have patches of unreplaced banded hematite-quartzite in it.

Bonai State.

The main iron-ore range in Bonai State has been divided into the following six sections for convenience in making the estimates, but rich hematite occurs at the top of the range, for practically the whole of the distance from the Singhbhum-Keonjhar boundary to just north of the Kurhadi river, a distance of about fourteen miles :—

1. *Singhbhum-Keonjhar boundary to Samaj* nadi *gorge.*
2. *Samaj* nadi *gorge to quartzite break (about three miles).*
3. *Quartzite break to path north of Samlaibar Pahar.*
4. *Samlaibar Pahar (about 1½ miles).*
5. *Bichakhani Pahar.*
6. *Dandrahar Pahar.*

The range consists mainly of banded hematite-quartzite striking north-east to south-west, and dipping about 70° to the north-west. There are two or three points where there are breaks in the ore, and where replacement of the quartzite has not taken place.

The first and most northerly section in Bonai State stretches a distance of about three miles from the boundary to the Samaj river or *nadi*, and is a continuation of the main iron-ore range in Singhbhum. Where the stream cuts through the range is an excellent section of much folded banded hematite-quartzite, but no workable hematite is seen in the bed or banks of the river. High up on the range, both to the north and to the south of the river is rich hematite. The top of the range which varies from about 400 to 800 feet across is

largely covered but good hematite is exposed *in situ* in places and there is much rich hematite debris. The ore is of the porous laminated type, and has rather a shaly appearance.

The second section runs from the break in the ore at the Samaj *nadi* for about three miles to the south-west, to where there is another break in the ore-body, and includes the peaks Karaspani Pahar and Erua Pahar. Towards the south end of this three miles, replacement of the banded hematite-quartzite seems to be less complete than to the north, until at the break it seems that the hematite passes laterally into banded hematite-quartzite, which extends for about three hundred yards, and then again passes laterally into hematite. The actual junction showing the passage of one into the other is not seen owing to the covered nature of the ground. The ore just south of the Samaj *nadi* near the top of Karaspani Pahar is good rich massive steel-grey, but towards the south it seems more porous and laminated, and some of the bands contain martite crystals. The width of ore across the range here averages about six hundred feet, but it is largely covered with heavy forest, soil and hematite debris. The ore extends down both the east and west slopes for over a hundred feet before it gets covered with soil and hematite debris. On the lower slopes of Erua Pahar, a little manganiferous material is exposed, but it seems small in extent and of no economic value.

The third section runs from the banded hematite-quartzite break for about two miles towards the south, to the path passing over the range just north of Samlaibar Pahar, and rich hematite occurs for the whole of this length. It has practically the same strike and north-westerly dip as to the north, but towards the south the band of hematite and the range swings round slightly, and the strike becomes N. N. W. to S. S. E. The ore is similar to that noted further north, at times rich massive steel-grey, but generally rich laminated and often porous hematite, which in parts is much lateritised. It is well exposed on the east and west top edges of the range, but often becomes covered along the centre of the range with soil and hematite debris, the latter in some cases being cemented with lateritic material to form a consolidated ore. Towards the south end of this section, replacement has possibly not been so complete as in the northern part, and a good deal of covered ground occurs.

The fourth section continues southwards from the third section for about 1½ miles, and includes the peak Samlaibar Pahar.

Good hematite, lateritised in parts occurs along the whole of this section, and is well exposed in the Samlaibar Pahar, and in the small peak to the south. The laterite often shows a laminated character, and has evidently been formed from the laminated shaly-looking hematite. At Samlaibar Pahar good hematite stretches right across the range, which at this point is about eight hundred feet across, but on the east edge there is a cliff of laterite. At the south end of this section, there seems to be another break in the ore, where the Tensa-Dadan Raikela path crosses the range just north of Bichakhani Pahar (21° 52′ : 85° 09′). There are considerable quantities of rich hematite debris on the western slopes of this section.

In the fifth or Bichakhani Pahar section of about 1½ miles, the replacement at the north end has been somewhat imperfect, and Bichakhani Pahar is mainly banded hematite-quartzite, but rich hematite occurs just south of the Tensa-Dadan Raikela path. The lower slopes of the range are banded hematite-quartzite. The ground in the top centre of the range is largely covered, but rich hematite of the porous laminated type is seen on both east and west top edges, and probably extends right across the range except near Bichakhani Pahar. Towards the south, near where the Tensa-Barsua path crosses the range, replacement is again imperfect, and banded hematite-quartzite occurs with the hematite, but owing to the rocks being very covered, its extent is uncertain.

The sixth section runs south from the Tensa-Barsua path for about three miles, and includes the peak Dandrahar Pahar. Rich hematite, generally laminated and somewhat porous occurs at the top of the range for practically the whole of the three miles, but at Dandrahar Pahar, the ore is very massive rich steel-grey hematite dipping about 50° to the west, and forming a steep cliff on the west side. Some of this ore is magnetic, which is probably due to small crystals of magnetite. Ore can be traced down the western slopes for over three hundred feet. To the south, the ore passes laterally into banded hematite-quartzite. On the east top edges of the range, rich hematite occurs for about sixty feet before being covered, but lower down the slopes is a cliff of good hematite nearly fifty feet in height, below which the slopes are covered. In the Kurhadi Nadi, which cuts through the range at the south end of this section, there is a thickness of about 3,000 feet of banded hematite-quartzite exposed, dipping 60° in a westerly direction.

7. *Kandadhar Pahar.*

The Kandadhar Pahar peak is situated about a mile to the north-west of Rontha (21° 46′ : 85° 08′). The main mass of the hill consists of banded hematite-quartzite which forms steep scarps and cliffs on the western side. Iron-ore occurs at the top of the hill, and seems to be a replacement of the quartzite and of the shales which occur to the east. The rocks are rather folded at this point, but have a general dip of about 70° to the west or north-west. The ore, although often of good quality does not seem to be so massive as that in the main iron-ore range. It is well exposed at the north-west top corner of the hill where it forms a small irregular cliff. The ore continues, more or less lateritised, and often covered, to the small rise about three quarters of a mile to the north, where ore much bent about is seen *in situ*. The ridge which runs out to the south-east of Kandadhar Pahar towards Rontha is partially covered lateritised hematite, but good hematite is seen *in situ* in places although it seems to be rather shaly in appearance, and much bent about and broken up.

8. *Cheliatoka Pahar.*

Cheliatoka Pahar is one of the highest points of the area under description, and is almost the most southern point of the iron-ore range. The hill consists of banded hematite-quartzite, which forms very steep cliffs both on the east and west side of the hill. North-west of the peak is a waterfall which has a vertical drop of nearly three hundred feet. In the lower ground immediately to the north of the peak is good hematite, but owing to the covered nature of the ground its extent is somewhat uncertain, but it seems to run round the low ground towards Kumritar Pahar.

9. *Kumritar Pahar.*

Kumritar Pahar (21° 45′ : 85° 09′) consists of rich hematite, lateritised in parts, and this ore continues towards the north, to just east of the village of Fulihari (21° 46′ : 85° 10′). North-west of Kumritar Pahar is a good body of hematite, but the ground is very covered, and its extent is somewhat doubtful. A short distance below the top of the hill, the ground is covered with soil and good hematite debris, but on the southern scarp about forty feet of good ore is exposed before being covered. At the south-east corner of the hill, the ore is steel-grey in colour and is very massive.

North-west of Kumritar Pahar is a body of good hematite, but the ground is very covered, and its extent is somewhat doubtful.

A ridge just to the south-west of Fulihari contains some bands of hematite, but it appears to be interbanded with the banded hematite-quartzite, which forms the lower north-western slopes of the hills. In some of the streams, the hematite debris has been cemented together by lateritic material to form a consolidated ore.

10. Saraikela-Rontha path to Raisua-Lusi path.

At the edge of the scarp just to the east of Fulihari is a patch of unreplaced banded hematite-quartzite, but to the north-east of this, the scarp shows good iron-ore, which continues for about one-and-a-half miles to just before reaching the Raisua-Lusi path, where another small patch of unreplaced banded hematite-quartzite occurs. Good rich hematite can be seen down the face of the scarp before it gets covered. It can also be seen down the dip slope for over eight hundred feet before being covered with soil and rich hematite debris, which in parts is consolidated together. Lower down the dip slope is banded hematite-quartzite, dipping north-west.

On the ridge west of Lusi (21° 47′ : 85° 11′) are considerable quantities of hematite debris, and possibly some ore *in situ*, of the lateritised rusty-looking type, but it is impossibly without prospecting pits, etc., to get much idea of its extent.

11. Raisua-Lusi path to Jhubka-Dinakora path.

The direct distance between these two paths where they cross the scarp is just over three miles, but the Pahardo Pahar (21° 47′ : 85° 12′) ridge stretches out to the south-east, and replacement of the banded hematite-quartzite in this section seems very irregular. The south-east end of the Pahardo Pahar ridge is of extremely good massive steel-grey hematite, which on the north-east side is lateritised, but the ridge and hill towards the north-west becomes covered with soil and hematite debris, much of which has become consolidated.

Replacement does not seem to have been very complete just to the west of Patripos Pahar (21° 48′ : 85° 13′), and a large part of the hill is banded hematite-quartzite. The edge of the scarp and the small hillock to the west of Patripos Pahar contains occasional exposures of hematite, with a small twenty foot cliff of good ore

on the south side, but the hill is largely covered with laterite and hematite debris, especially on the north-west slopes.

The scarp on the east side of Patripos Pahar to the Jhubka-Dinakora path is largely covered, but contains good laminated, rather shaly-looking hematite, *in situ* in places, but it is largely lateritised towards the north-east and towards Tumka Pahar.

The hills north-west of Tumka Pahar are of lateritised hematite at the top, and banded hematite-quartzite lower down. The ore has a shaly appearance, and consists of thin layers of grey hematite alternating with thin layers of rather porous hematite and laterite.

12. South-east of Jhubka.

South-east of Jhubka (21° 50′ : 85° 13′) the ground is very covered and lateritised, but some small bodies of hematite occur, whose boundaries are rather indefinite.

13. Ungarpora Pahar.

The Ungarpora ore-body occurs in a ridge about a mile to the west of Raikela (21° 53′ : 85° 12′). The ridge is very much covered with soil and lateritic debris, and has been largely hill or dry cultivated, but at the top good laminated hematite occurs striking nearly north to south and dipping about 70° to the west. The ore-body stretches for over a mile in length, and along the same strike about half a mile to the south, is a small exposure of hematite, but the intervening ground is covered. Laterite occurs on the top east and west edges of the hill, and the slopes show several outcrops of laterite, some of which may cover rich hematite.

14. Rengarbera.
15. North-west of Kasira.
16. South-west of Kasira.

The low hillocks round Rengarbera (21° 58′ : 85° 16°) and to the west of Kasira (21° 56′ : 85° 15′) are generally ferruginous sandy shale, but they are often covered with hematitic and lateritic debris. At the tops of the hillocks hematite is occasionally seen *in situ*, but the amount is not very large, although there seems to be a fair quantity of hematite debris. The ore does not seem to be of very good quality, is rather porous and of the shaly-looking type, and appears to have replaced the shale.

17. West of Koira.

The high ground between Koira (21° 54′ : 85° 15′) and Nawagaon (21° 54′ : 85° 14′) is covered with laterite and rich hematite debris. At the top easterly edge is a small exposure of hematite *in situ*, and other small patches of hematite may be *in situ*, but prospecting pits are necessary to prove that they are. The slopes on the Nawagaon side of the hill are laterite and laterite debris.

18. South of Kalmang.

The hills to the south of Kalmang (21° 57′ : 85° 19′) are largely covered with hematite and laterite debris, but a small body of good shaly-looking hematite occurs. The ground is largely soil covered, so that the extent of the ore-body is doubtful, but it is not very large.

19. East of Mankarnacha Peak.
20. West of Badamgarh Pahar.

Between Mankarnacha Peak (21° 48′ : 85° 14′) and Badamgarh Pahar are several ore-bodies, the boundaries of which are often indefinite, owing to the covered nature of the ground, and to the irregularity of the replacement of the banded hematite-quartzite. The ore is generally porous laminated, and of good quality, but in parts is much lateritised.

39. North-west of Khajurdi.

At the top of the ridge stretching from north-west of Khajurdi towards Balia Pahar (21° 51′ : 85° 18′) is lateritised hematite. The ore in parts is of good quality, but it is mostly of the porous laminated shaly-looking type, and is usually much lateritised. The area is largely covered with soil and good hematite debris.

40. Badamgarh Pahar.

Badamgarh Pahar (21° 49′ : 85° 16′) is partly in Bonai State and partly in Keonjhar State, and it contains a large body of rich ore. On the south-east, hematite is exposed for about one hundred feet down the scarp before it is covered. The ore is somewhat lateritised at the surface and replacement has been irregular along the scarp to the north-east. Some of the ore is of the massive steel-grey type, but most of it seems to be of the porous laminated type.

41. Between Badamgarh Pahar and Balia Pahar.
43. Between Balia Pahar and Malangtoli.

The country between Badamgarh Pahar and Balia Pahar (21° 51′ : 85° 18′) and between Balia Pahar and Malangtoli (21° 49′ : 85° 19′) is very rough and covered with thick forest. With the old maps available, it was impossible to get much of an idea of quantities of ore, but rich hematite, often of the massive steel-grey type occurs along the ridge which stretches between the first mentioned two hills. Most of the ore is in Bonai State, but some of it is over the boundary, and is in Keonjhar State.

There is a good deal of ore also between Balia Pahar and Malangtoli, and the ridge near Malangtoli contains good laminated porous hematite. The ridge 1½ miles east of Malangtoli also contains good hematite.

42. Balia Pahar.

The Balia Pahar ridge has a good rich hematite ore-body at the top which stretches for about 1½ miles, with a variable width, averaging say 600 feet. Massive steel-grey hematite occurs, but there are also large quantities of the porous laminated type, which is often partly lateritised. The lower slopes of the ridge are banded hematite-quartzite.

44. North of Mitihurda.

On the ridge running north of Mitihurda (21° 50′ : 85° 20′) is lateritised hematite with some irregular patches of unreplaced banded hematite-quartzite, the whole being largely covered with lateritic soil and hematite debris. Some rich massive steel-grey hematite occurs, but its extent is doubtful. Most of the hematite exposed is of the porous laminated shaly-looking type.

Kodalia (21° 52′ : 85° 20′) to the north of Mitihurda is situated on a lateritic plain, but the hill to the north-west has a capping of good porous hematite, which down the slopes is covered with lateritic material and hematite debris. The lower slopes of the hill are banded hematite-quartzite.

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GEOGRAPHICAL INDEX.

MGIPC—M—VIII-4-10—4-9-34—850.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

VOLUME LXIII.

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1934.

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PART 2.

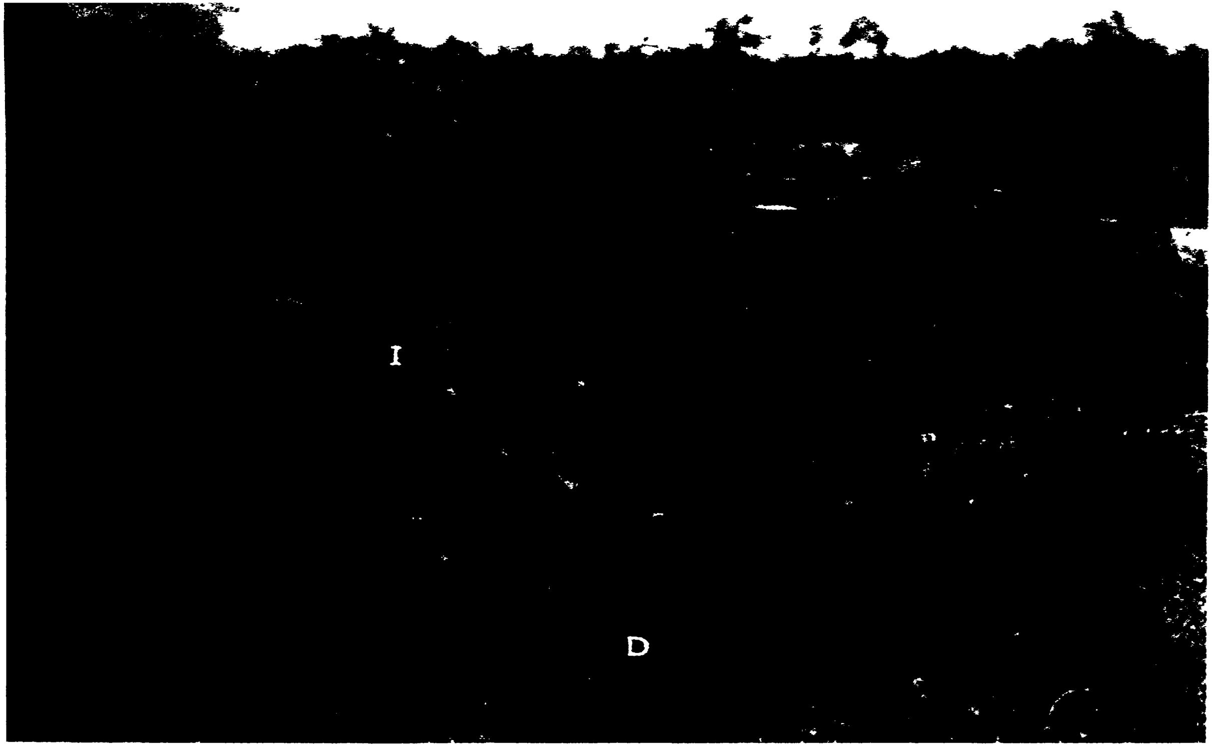
MGIPC—M—VIII-4-10—5-9-34—850.

H C. Jones, Photo *G. S. I., Calcutta.*

IRON-ORE SERIES (I) OVERLYING OLDER DHARWARS (D) AND GRANITIC ROCK (G), DEO RIVER, NEAR MUNGRA.

H. C. Jones, Photo. *G. S. I., Calcutta.*

WISPS OF OLDER DHARWAR QUARTZITE (D) CAUGHT UP BY GRANITIC ROCK (G), DEO RIVER, NEAR MUNGRA.



H. C. Jones, Photo *G. S. I., Calcutta.*

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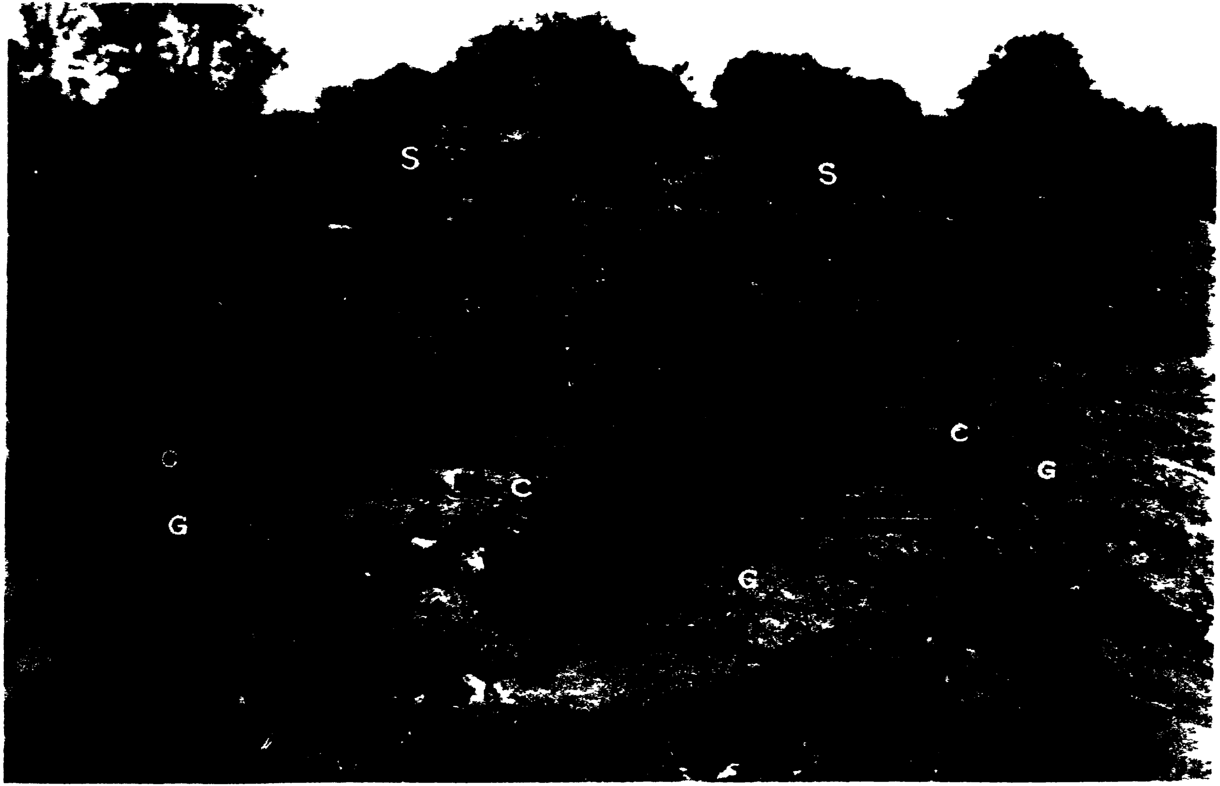

H C Jones, Photo *G S. I., Calcutta*

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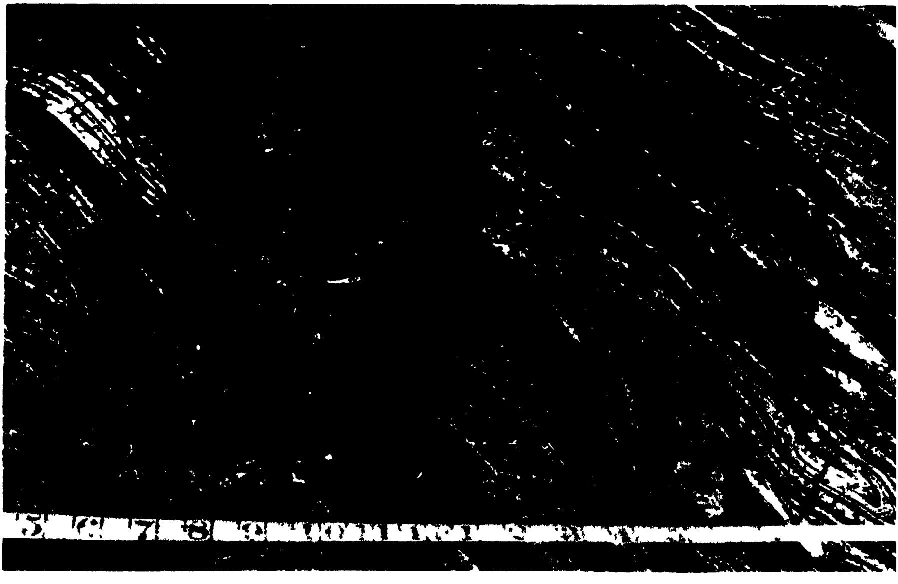

H. C. Jones, Photos. *G. S. I., Calcutta*

FIG 2. FOLDING AND FAULTING WITH FAULT BRECCIA IN BANDED HEMATITE-QUARTZITE, KURHADI *NADI*, DADAN RAIKELA.

H. C. Jones, Photo

G. S. I., Calcutta.

FOLDING IN BANDED HEMATITE-QUARTZITE, SAMAJ *NADI*, NEAR TODA.

H. C Jones, Photo *G. S. I., Calcutta.*

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H. C. Jones, Photos. *G. S. I., Calcutta.*

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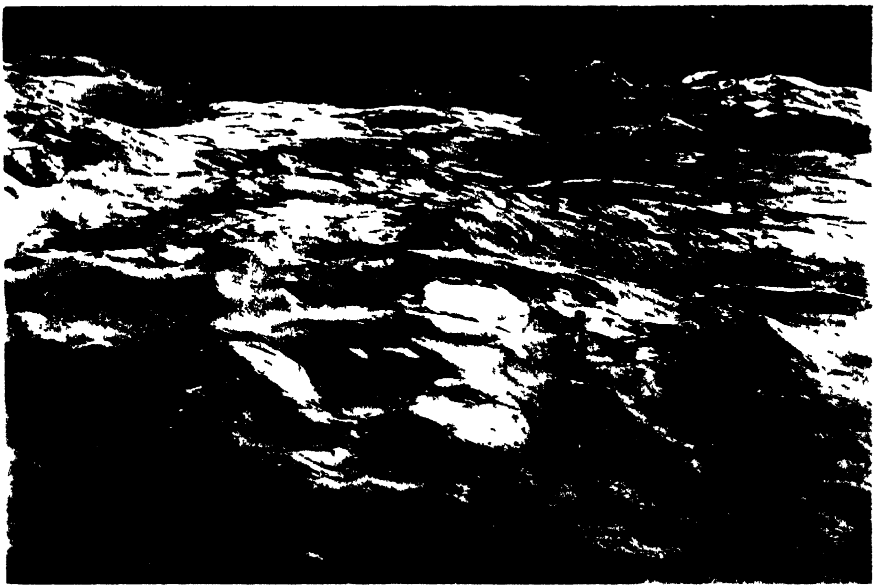

H C. Jones, Photos *G S I., Calcutta*

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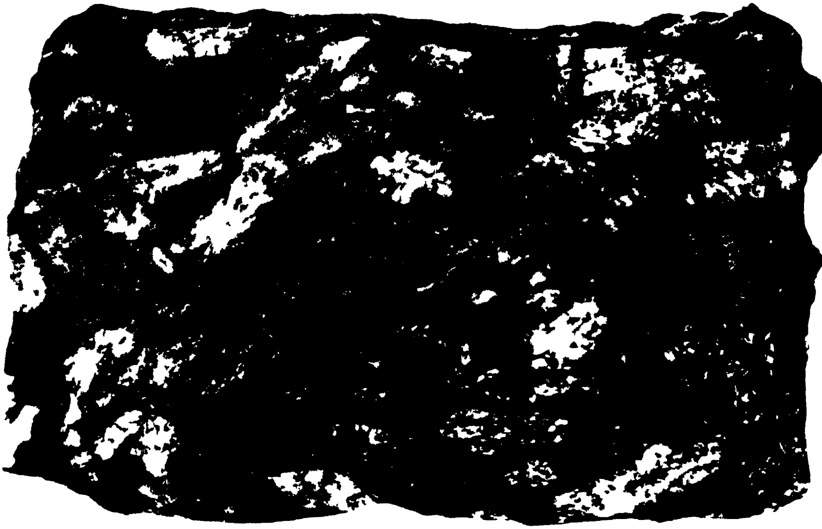

H C I n I i

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Natu al s z

M. S Krishnan, Photo *G. S I, Calcutta*

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A

H C Jones Photo

G S I., Calcutta.

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H. C. Jones, Photo. G. S. I., Calcutta.

HEMATITE CLIFF, JODA EAST.

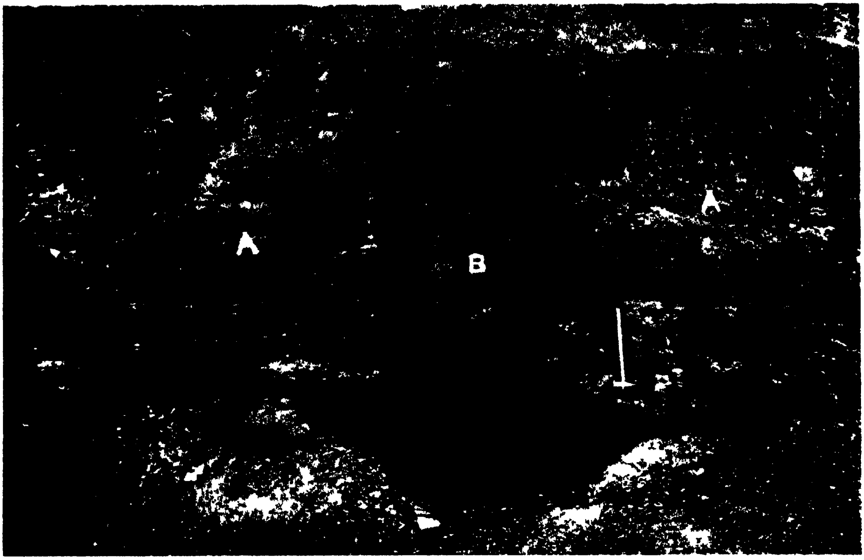

FIG 1 LAMINATED HEMATITE (A) PASSING LATERALLY INTO BLUE POWDER HEMATITE (B), BELOW HOSPITAL NOAMUNDI MINE

H C Jones, Photos *G S I., Calcutta*

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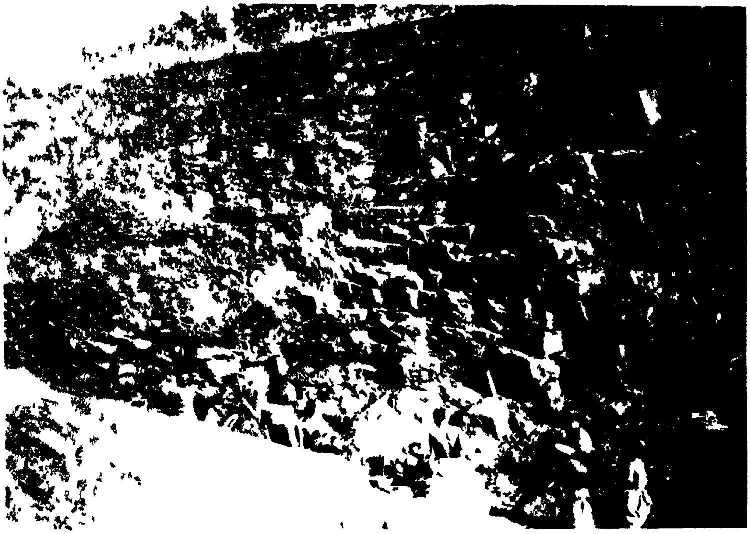

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H. C. Jones, Photos *G. S. I., Calcutta*

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H. C. Jones, Photos. *G. S. I., Calcutta*

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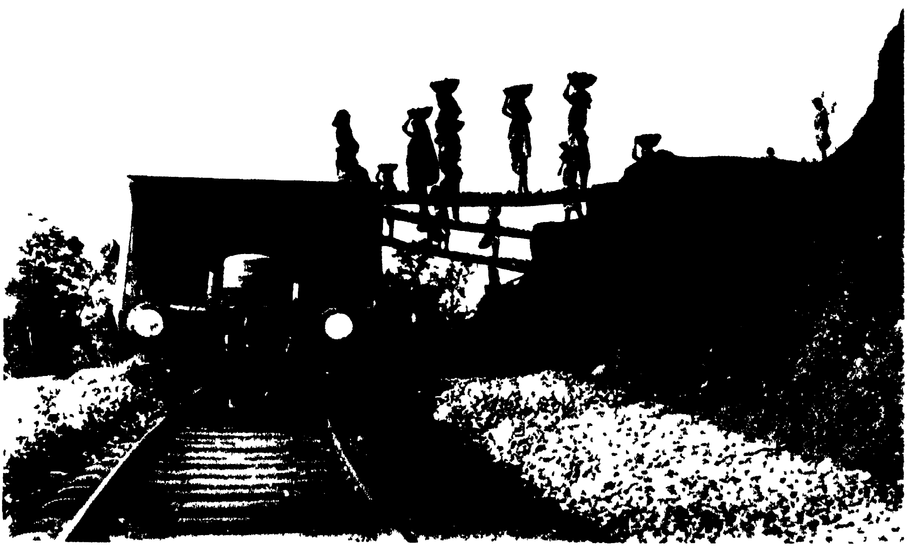
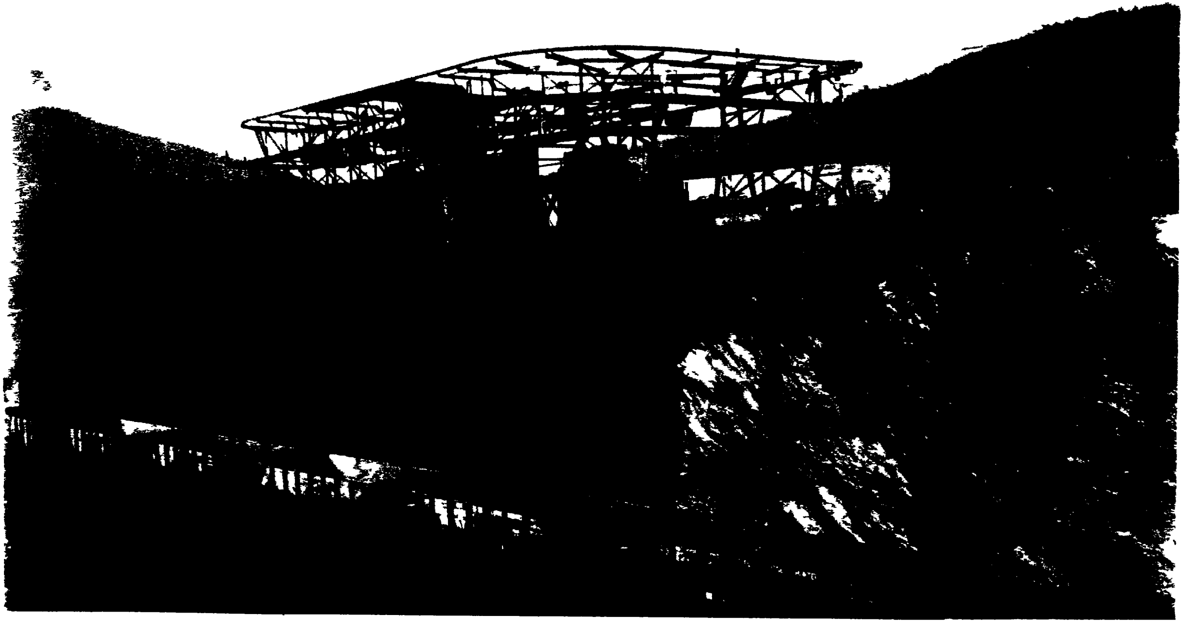


H C Jones Photos *G S I, Calcutta*

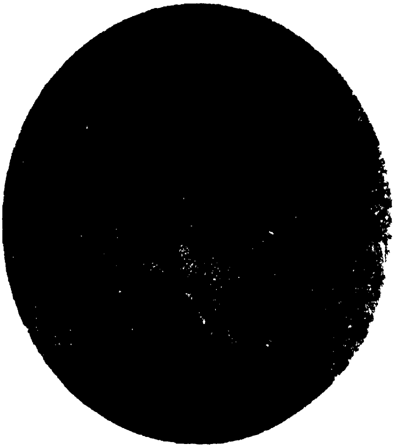
FIG 2 HAND-LOADING IRON-ORE, HILL 1, NOAMUNDI MINE



H C. Jones, Photo

G. S I., Calcutta

LOWER ORE BUNKER AND ROPEWAY, INDIAN IRON AND STEEL COMPANY, LIMITED, GUA



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H C. Jones, Photomicros

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G S. I, Calcutta

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

VOLUME LXIII, PART 3.

THE STRATIGRAPHY OF SOUTH SINGHBHUM. BY J. A. DUNN, D.Sc., D.I.C., F.G.S., F.N.I., *Superintending Geologist, Geological Survey of India.* (With Plates 33-37.)

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1940.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA

THE STRATIGRAPHY OF SOUTH SINGHBHUM. BY J. A. DUNN, D.Sc., D.I.C., F.G.S., F.N.I., *Superintending Geologist, Geological Survey of India.* (With Plates 33-37.)

I. INTRODUCTION.

The nature of the problem.

Two *Memoirs* on the stratigraphy of Singhbhum have appeared in recent years, one dealing with North Singhbhum,[1] and the other with South Singhbhum.[2] A third, dealing with East Singhbhum, has been in course of preparation for 5 years, but has been delayed largely because of the difficulties in correlating the rocks of East Singhbhum with those of South Singhbhum. In a *Memoir* on the economic geology of East Singhbhum[3] the stratigraphy of that region, based on views to date, was summarised. Close personal acquaintance with the whole of North and East Singhbhum led me to recognise a fairly well-defined succession there, a succession to which I could see little alternative. It appeared to me that a more critical examination of the facts in South Singhbhum might be helpful. This is an area with which, apart from two seasons at the commencement of my service in India and occasional visits to iron-ore mines, I had not such a complete acquaintance. Accordingly, the map and sections which accompany Jones's *Memoir* on South Singhbhum, were critically reviewed and the facts which emerged, as well as certain outcrops which were seen during a brief visit to Gua, indicated that something had been overlooked in the early mapping.

[1] J. A. Dunn, *Mem. Geol. Surv. Ind.* LIV, (1929).
[2] H. C. Jones, *Mem. Geol. Surv. Ind.* LXIII (2), (1934).
[3] J. A. Dunn, *Mem. Geol. Surv. Ind.* LXIX (1), (1937).

The succession of sedimentary rocks established by H. C. Jones was as follows:—

Upper shales, lavas and ash beds Banded-hematite-quartzites . . Lower shales with sandstones . Limestone . . . . . . Purple sandstone and conglomerate	Iron-ore Series (Newer Dharwar).
Older Metamorphic Series . .	(Older Dharwar).

This succession was founded on a section along the Deo *nadi* near Mungra (22° 15′, 85° 39′), where the basal conglomerate, containing pebbles of banded-hematite-quartzite, jasper and quartz, was seen to rest on the upturned edges of the granitised Older Metamorphic rocks, which here consist of banded-hematite-quartzite, jasper, hematite-schists and hornblende-schists, with quartz veins. According to Jones there followed, west from this conglomerate, a complete sequence right up to the banded-hematite-quartzite of the Iron-ore Series. This at once indicated that banded-hematite-quartzites occurred in both Series, a view to which there could be no legitimate objection. Jones had also recognised the existence of other conglomerates, which he regarded as intraformational in the upper part of the Iron-ore Series.

Examination of the map indicated the curious anomaly that, to the south, the great thickness of lower shales suddenly disappeared at the iron-ore deposits near Noamundi, and the banded-hematite-quartzite there rested directly on a dolerite "sill" and apparently, in places, on the basal conglomerate. To explain this in his section, Jones postulated a great fault up which the dolerite came. But examination of the edge of the banded-hematite-quartzite, as mapped, made such a simple fault hypothesis unlikely.

Further, Jones indicates in his sections that several of the iron-ore deposits represented caps of anticlines peeping above the upper shales, but some of these upper shales of the sections are actually along the strike-continuation of lower shales on the map. Some of the anomalies could be explained by overfolding—which is prevalent throughout the area—but so many anomalies accumulated that the sections postulated became obviously unlikely.

Perhaps the most remarkable anomaly in Jones's sections concerns the phyllites on either side of the Iron-ore Range. Those on the east side he refers to, in the text, as the lower shales, whereas in the sections he shows them as upper shales. The phyllites,

lavas and ash beds on the west side of the Range are described in the text as being higher in the sequence than the banded-hematite-quartzite, yet the sections show them as lower.

Percival[1] and Spencer[2] had criticised Jones's interpretation of the "intraformational conglomerates" and had referred to obvious unconformities. Percival had also suggested that all of these conglomerates, including the one at the Deo *nadi*, might be of the same horizon. Unfortunately no map was produced to support this suggestion. Perhaps, also, Percival clouded the issue by indirectly expressing uncertainty whether the Deo *nadi* conglomerate was of the same horizon as the basal purple sandstone which occurred along the base of the shales and limestone to the north, near Kondoa. Indeed, Percival remarked that he had not seen any other rock overlying the conglomerate of Deo *nadi* yet shales and limestone can easily be seen there.[3] As these were facts which were entirely certain, without equivocation, to those of us who had followed and mapped this base, Percival's view was not immediately investigated. The account which follows removes all of Percival's difficulties, for the shales and limestones overlying the conglomerates are grouped with the latter as a distinct series, younger than the Iron-ore Series[4].

During a visit to Gua iron-ore mine I noticed a conglomerate resting with profound unconformity on rocks which were very similar to some of the "Older Metamorphic" rocks, and these conglomerates were right in the middle of the Iron-ore Series tract. More conglomerates were examined in a few other places and the view gradually formed that either Older Metamorphic rocks cropped up here and there in the Iron-ore Series area, or else the banded-hematite-quartzite, iron-ores and cherts of the Iron-ore Series were the same as the similar rocks in the so-called "Older Metamorphic Series". The latter view was favoured and noted in the Annual Report for 1937,[5] as it appeared to fit the succession known in East Singhbhum.

[1] F. G. Percival, "The iron-ores of Noamundi", *Trans. Min. Geol. Inst. India*, 26 (3), 252-261, (1931).

[2] E. Spencer, *Trans. Min. Geol. Inst. India*, 26 (4), 322-323, (1932).

[3] F. G. Percival, *loc. cit.*, p. 260.

[4] This memoir was completed in March 1939. Since then Percival and Spencer have contributed a further paper on this area, "Conglomerates and lavas in the Singhbhum-Orissa Iron-ore Series", *Trans. Min. Geol. Met. Inst. India*, 35 (4), pp. 341-363, (1940). It appeared too late for any comment to be made here, but it may be said that the evidence supplied in this memoir provides the full answer to the points on which we differ.

[5] *Records Geol. Surv. India*, 73 (1), p. 27, (1938).

Accordingly, in December 1938, and January 1939, the basal conglomerate was followed south from Chaibasa to Noamundi, correcting the earlier mapping where necessary. Jones had mapped this conglomerate up to the east side of the Noamundi mine ridge, but on his map it was shown to suddenly stop at this point. Actually the conglomerate can be followed without the slightest difficulty for another three miles west, where it swings sharply north, and was carefully mapped for a further five miles to the northern edge of sheet 73 F/8. Time did not permit of a continuation of the mapping, but at its northernmost point the sandstone was still well-defined. Its survey will be continued in the near future.

North of Noamundi mine the conglomerate strikes due west, at right angles to the north-south and N.W.-S.E. strike of the banded-hematite-quartzite to the south. The banded-hematite-quartzite dips westward at a steep angle; the overlying conglomerate dips gently north, at an angle up to 10°, dipping conformably beneath a group of flat-lying shales. This is the decisive section, and it is regrettable that a day's mapping had not been done on the conglomerate here years ago.

Section after section was examined, each showing the unconformity at the base of this conglomerate. I do not think that I have seen, in any country, such a remarkably clear series of sections exposing so beautifully such an unconformity. These sections leave no alternative interpretation.

Proceeding from Chaibasa to the south-west, the conglomerate rests unconformably in turn on granite, granite and hybridised schists, lava and tuffs hematitised below the unconformity, banded-hematite-quartzite and finally phyllites. Once the conglomerate overlaps on to the phyllites it becomes more and more acutely folded and its contortions increasingly difficult to follow.

These facts, then, indicated that the "basal conglomerate" is not the base of the series which contains the banded-hematite-quartzites, the main country-rock of the iron-ores, but is the base of a much younger system. Difficulties of nomenclature then arose—for which group were we to retain the name "Iron-ore Series"? It was obviously desirable to keep this name for the group containing the main iron-ore deposits. The younger group was designated the Kolhan Series, as it is so clearly developed in that part of Singhbhum known as the Kolhan.

I have remarked that the Kolhan Series rests unconformably on the Singhbhum granite. Evidence had been given by Jones that the Singhbhum granite was intrusive into the basal sandstone-conglomerate. Although the granite had thoroughly impregnated and hybridised the schists in such places as the Deo *nadi* section (*see* Plates 13, 14, 15, *Mem.* LXIII (2)), and had not penetrated the conglomerate there, Jones still regarded the granite as younger than the conglomerate. This explanation could scarcely be valid for such a constant relation, and I had in recent years concluded that there must be two granites—a pre-conglomerate granite which had hybridised the schists, and a later granite which had intruded the conglomerate and overlying shales. The localities quoted in Jones's memoir as showing intrusion of the conglomerate were recently re-visited, and the evidence was found to be either unsatisfactory or had been previously incorrectly interpreted. The contact between granite and the Kolhan basal bed was critically examined at innumerable places, and nowhere could any evidence of an intrusive relation be established. The unconformity is clearly marked in many places, truncating granite, schist inclusions and hybrids with granite veins, and even the old pebbly surface is often visible. The granite is, however, intrusive into the Iron-ore Series.

The term Older Metamorphic Series (or Older Dharwars of Jones) had been applied to certain banded jaspers, and hornblende-schists, on which the "purple sandstone" rests north of Jagannathpur. The possibility of the existence of an older metamorphic series elsewhere still remains, but, as will be seen later, these metamorphic rocks in South Singhbhum are believed to be metamorphosed Iron-ore Series rocks.

We may now compare the old and new interpretation of the two series in South Singhbhum, leaving the sequence in the revised Iron-ore Series to be discussed later :—

	Jones.	*Dunn.*
Iron-ore Series (Newer Dharwar).	Upper shales, lavas and ash beds.	Kolhan shales.
		Kolhan limestone.
	Banded-hematite-quartzite.	Kolhan sandstone-conglomerate.
		(unconformity)
	Lower shales.	Iron-ore Series.—Phyllites, banded-hematite-quartzite, tuffs, cherts, and lavas.
	Limestone.	
	Purple sandstone-conglomerate.	

(unconformity)

Older Metamorphic Series (Older Dharwar).

In a few places the remnants of a much later sedimentary rock have been preserved. This is a very distinctive friable grit consisting of sharply angular quartz grains in a limonitic matrix, and rests on top of any of the earlier rocks. It may even be Tertiary in age.

We may now complete the sequence in South Singhbhum by the addition of the Singhbhum granite and the Newer Dolerite :—

? Tertiary grit.
Newer Dolerite (see page 363).
Kolhan Series.
(unconformity).
Singhbhum granite.
Iron-ore Series.

Within this sequence there were at least two great periods of earth-movement. The first of these gave rise to the folding and partial metamorphism of the Iron-ore Series, a metamorphism which was increased later wherever it was closely intruded by the Singhbhum granite. A further period of folding followed the deposition of the Kolhan Series on the denuded older rocks. Where the basement was granite this rock resisted the post-Kolhan fold movements, so that there the Kolhan beds were little folded (except in the vicinity of normal faulting as to the north of Hat Gamaria). But where the basement of the Kolhan Series was Iron-ore Series phyllites, the latter yielded readily to the later fold movements and the overlying Kolhan rocks were in places closely folded. These fold-movements followed and accentuated the trend lines of the older post-Iron-ore Series movements, so that the Kolhan rocks, where closely folded, tend to strike parallel with the Iron-ore Series rocks.

Correlation.

The question of the position which the Kolhan Series occupies in the Pre-Cambrian of the Indian Peninsula must be left in abeyance. Surmises as to correlation with the Cuddapahs are not only idle but, in the present state of our knowledge of Pre-Cambrian and Archean rocks in the Peninsula, may be harmful. Such surmises overlook the growing probability that the original essential division of these ancient rocks into Archeans, Cuddapahs and Vindhyans, is far from being the whole story. The arguments

upon which our very definitions of the Archeans are based form a vicious circle. Within the Archeans themselves, or rather those rocks which we have accepted as Archean, there are unconformities of quite a profound nature, and certainly overlaps.

It is also for this reason that I have finally rejected the use of the general term *Dharwar* for the Archean schists of the Peninsula. It infers unwarranted correlations with the little-known rocks of the Dharwar type area. The geology of Rajputana, Central Provinces and Chota Nagpur is known in far greater detail than is that of Dharwar, and in some of these areas we know that we are dealing with several systems of schists of which any one system may or may not be the equivalent of the Dharwars. It is preferable that we should still retain our local names, restricting the term *Dharwars* to the schists of South India, and, if a general term is at times required to include these several systems, *Archean* remains entirely suitable. In view of our uncertainty of definition of the term *Archean* or of the *Eparchean unconformity*, I am tempted to go even further and suggest that the one term *Pre-Cambrian* be used in India as the general term for all systems downwards from the Vindhyan inclusive. The old term *Purana* in any case need not be retained, there is no longer any necessity for it.

The map.

Although the base of the Kolhan Series has been resurveyed southwards from Chaibasa (at latitude 22° 33′), only a part of the resurvey, south of latitude 22° 15′, is reproduced in the accompanying map, Plate 33. This is the essential portion illustrating the unconformable relation of the Kolhan Series to the Iron-ore Series. The eastern rim of the banded-hematite-quartzite, many miles to the south, was also re-mapped to show more correctly the true relation between Kolhan sandstone, lava, banded-hematite-quartzite and phyllite, but, in order to reduce the published map to a reasonable size, these further alterations in Jones's map could not be included. In reading this paper reference should be made to Jones's map for places outside of the smaller map reproduced herewith.

The accompanying map, reduced from the scale of one inch to half inch to the mile, is based partly on the recent survey and partly on the older map accompanying Jones's memoir. The delineation of the boundary of the Kolhan Series from the Deo

nadi westward is entirely of the recent survey. For the Iron-ore Series I have taken the older map (which was based on the work of the following officers:—Jones, Dunn, Hobson and Krishnan), but have made many corrections, particularly between Jamda and Gua. Part of the area, which I have not recently re-visited, has been taken from the early map in order to show the trend of the Iron-ore Series in the vicinity of the Kolhan Series. The change in the boundary of the lava south of Dangoaposi is made on the basis of new evidence; I was personally responsible in 1922 for the delineation of this boundary on the old map and offer longer experience as an execuse for my change of opinion.

The revised maps, outside of the area shown on Plate 33, can be consulted at the office of the Geological Survey of India, by those who may be interested in the geology of this region.

Foreword to descriptions of the rock series.

As the main object of this paper is to describe the new Kolhan Series, it would have been preferable, perhaps, to describe that series first in the following pages. However, I prefer to adhere to the logical method of describing in succession each group in the stratigraphic sequence from the oldest to the youngest—section III, dealing with the Kolhan Series, is the most important. The other sections have been written in order to fill some of the gaps left by Jones's memoir.

II. THE IRON-ORE SERIES.

Structure and sequence.

It will be appreciated that in view of the new grouping of a large part of Jones's Iron-ore Series with the Kolhan Series, the stratigraphical sequence previously accepted within the Iron-ore Series now collapses. It is necessary, therefore, to try to re-erect the sequence table within the Iron-ore Series in terms of the new facts which have emerged. It may be said at once, that, within the area surveyed in South Singhbhum and the adjoining part of Keonjhar, no certain sequence has been established. Possibly, further work to the south, in Keonjhar, will eliminate in the near future the doubtful points in one or other of the alternative sequences deduced herein. It must be emphasised, however, that this inability to determine the correct sequence within the Iron-ore Series is entirely independent of the thoroughly established unconformity between the Iron-ore Series and the Kolhan Series.

From Jones's map it will be seen that the main outcrops of banded-hematite-quartzite form an elongated horseshoe, open to the north and closed to the south in Bonai and Keonjhar. The western rim of this horseshoe is the Iron-ore Range, the backbone of which is a more or less straight and continuous zone of banded-hematite-quartzite. The eastern rim is, at its northern end at Noamundi mine, some eight miles from the Iron-ore Range, and in contrast to the western rim is represented by outcrops of banded-hematite-quartzite of very varying widths. Smaller outcrops of banded-hematite-quartzite occur within the area enclosed by the horseshoe; this area consists largely of phyllites with tuffs, lavas and some cherts, and, in addition, occasional outliers of Kolhan rocks. On the western side of the horseshoe there is a wide area of lavas between which and the banded-hematite-quartzite there is a zone of phyllites increasing in width to the north. On the eastern side of the horseshoe there is again a wide area of lavas, with occasionally a thin zone of phyllites intervening between them and the banded-hematite-quartzite. Recent work by Mr. B. C. Gupta has indicated that further south these lavas to the east continue around the horseshoe and, although the mapping is not yet complete, they obviously join with the lavas on the western side of the horseshoe.

Dips are generally persistently to the north-west, which is the prevailing direction of overfolding in the area. Sometimes, as in the quarry faces on the ridge at Gua, acute recumbent folds may be

seen to lie horizontally upon each other, the overfolding always being from north-west to south-east.

It has not yet been determined whether this horseshoe represents a geosyncline pitching to the north and overfolded along its western limb, or whether it is a geoanticline pitching to the south and overfolded along its eastern limb. The general sequence within the Iron-ore Series in South Singhbhum will depend upon the interpretation of this structure : if it is a geosyncline the sequence on the eastern rim will be normal, and if a geoanticline the sequence there is inverted.

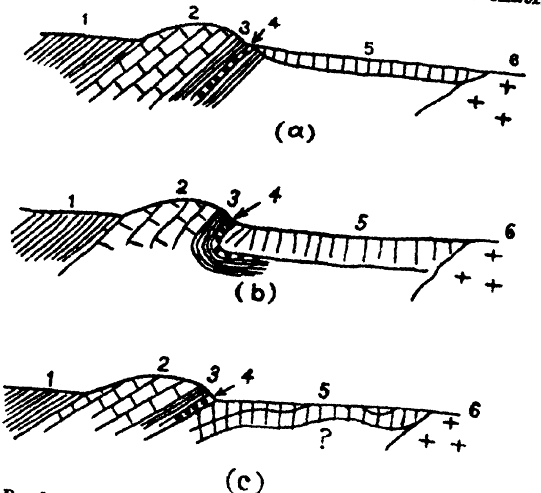
Whichever may be the correct structure the mapping illustrates one essential relationship : either the lava overlaps the banded-hematite-quartzite or the banded-hematite-quartzite overlaps the lava, depending upon which is higher in the sequence. Nevertheless, both have been subjected to the same fold movements, and their boundary north of Noamundi mine is crossed almost at right angles by the unconformity below the much later Kolhan Series. Compared with this latter unconformity, the overlap between the lavas and banded-hematite-quartzite is slight, and the lavas, phyllites and banded-hematite-quartzites are all closely related to each other, sufficiently so for the lavas to be grouped as part of the Iron-ore Series here.

Examining the rock relations along the eastern rim of the horseshoe, at Noamundi, three possible sections may be drawn across the mine ridge : (*a*), (*b*) and (*c*) of fig. 1.

Consider, first, section (*a*), in which the lava is shown as being younger than the banded-hematite-quartzite and the thin zone of phyllitic tuffs (" Mohudi shale " of Percival), resting on their tilted and denuded edges. In the railway cutting at Sangramsai (22° 10′ ; 85° 30′) the lava and interbedded tuffs, with also an interbedded conglomerate (*not* to be confused with the Kolhan conglomerate), dip at 30° to the west, apparently below the eastern side of the " Mohudi shales " and banded-hematite-quartzites. Wherever any relation can be seen along the western edge of this lava, it shows this parallel relation to the " Mohudi shales " and overlying banded-hematite-quartzite. Section (*a*) cannot be accepted.

Between sections (*b*) and (*c*) there is no certainty of choice as overfolding is prevalent in the area. Whatever evidence there is available, appears to be weakly in favour of the lava being stratigraphically below the banded-hematite-quartzite. Near the western end of the railway cutting on the east side of the stream, and south

of Sangramsai village, there is a conglomerate, consisting of quartz and quartzite pebbles in a decomposed tuff or lava matrix. Below



1—Phyllite. 2—Banded-hematite-quartzite. 3—Tuff-phyllite. 4—Sangramsai conglomerate. 5—Lava. 6—Granite.

FIG. 1.—Alternative sections across lava east of Noamundi.

this conglomerate only lava is to be found in the cutting, but above it tuffs (the "Mohudi shales") are interbedded with altered lava—this conglomerate has been taken as the base of the "Mohudi shales" which grade conformably towards their top through cherts to the banded-hematite-quartzite. The conglomerate represents, of course, an interval between flows and tuff—it has not been found elsewhere in south Singhbhum. It should not be given undue stratigraphic significance as, with overfolding, it could perhaps be regarded as the top of the tuff and the base of the lava! Similarly the gradation at the top of the "Mohudi shale" through chert, coarse banded jasper to banded-hematite-quartzite, should be given no stratigraphic significance.

Along the whole length of the western edge of this lava so far traversed, some 25 miles, every dip of immediately overlying phyllites [except a vertical cleavage dip at Inganjoran (22° 01′; 85° 28′)] and banded-hematite-quartzite is westward, and at an angle invariably less than 45°, often less than 30°. If the sequence here were inverted we might, perhaps, expect to find an easterly dip somewhere along the boundary. Also, on the western side of the east ridge at Noamundi, the "Mohudi shales" dip at 45° westward where they

are in contact with the banded-hematite-quartzite, but tracing them around the northern end to the eastern side of the ridge the dips gradually flatten until they are less than 10° westward, fig. 2. If the sequence is not normal here, but inverted, then the overfolding is recumbent. Further east we find that, wherever visible, the interflow surfaces in the lava are gently undulating.

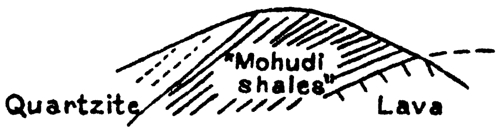


FIG. 2.—Section across north end of Noamundi ridge.

The evidence is not conclusive, but along this eastern rim it suggests that the sequence is :—

Banded-hematite-quartzite.
Phyllites (tuffs), impersistent.
Lavas.

I have not examined the rocks along the western rim of the horseshoe, that is, along the western side of the Iron-ore Range, but Jones shows all the dips as westerly with a zone of phyllites, intervening between the lava and banded-hematite-quartzites, rapidly increasing in thickness northwards. Providing the banded-hematite-quartzite of the Range is not in the form of a narrow elongated syncline, then the apparent sequence would be :—

Lava.
Phyllite.
Banded-hematite-quartzite.

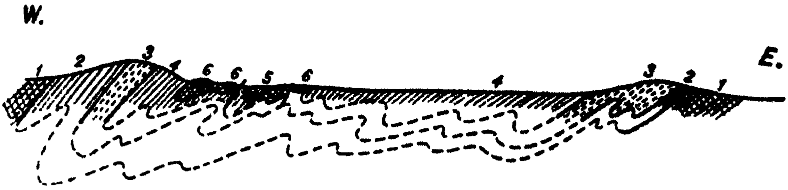
Within the central area enclosed by the horseshoe there are large areas of lava and banded-hematite-quartzite, as, for example, to the west and south-west of Barabil. The relation of these is similar to that between the lavas and banded-hematite-quartzites around the rim of the horseshoe, suggesting that the main group of lavas forms a single stage either above or below the banded-hematite-quartzites. This does not deny the probability, however, that additional impersistent lavas are interbedded with the phyllites.

Most of the central area within the horseshoe appears to be occupied by phyllites. Jones's map, however, gives an erroneous

impression of the extent of these phyllites between Noamundi and the Iron-ore Range, as by far the greater part of the area coloured as phyllite is thickly covered with alluvium, hill-wash or laterite. I have only examined in detail a small part of the less covered area, between Noamundi and Gua, and it will be observed from the accompanying map that there are quite extensive outcrops of altered lava which were not mapped by Jones, and many of the phyllites are really tuffs.

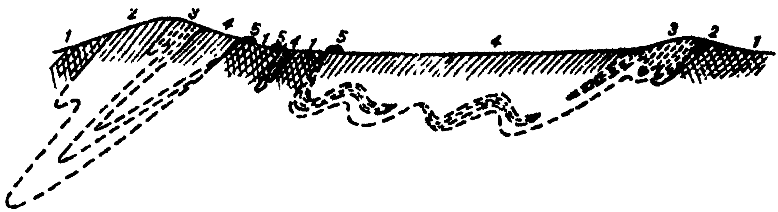
I must also refer to the possibility that Kolhan shales (which, even in the main basin, are often phyllites) are widely prevalent between Noamundi and the Iron-ore Range. We know that they do occur at Gua and also near Jamda station. In each case I have been forced to hypothesise a fault on one side of this Kolhan phyllite. That such faulting does exist is certain, but that I have placed the faults in the correct positions is far from certain. For example, I have presumed an overthrust fault on the western side of Jhiling Buru, cutting off the north-west dipping conglomerate there. This thrust fault is presumed to occur along the limb of a large fold between Raijori Buru ridge and Ranjajori Buru. There remains the possibility that the thrust fault is further west, at the base of the banded-hematite-quartzite, in which case all the phyllites on the eastern side of the ridge would be Kolhan. But, for structural reasons based on following these phyllites along the range, I do not think that this is probable, as the whole story of the relation between the Kolhan Series and the banded-hematite-quartzite would break down, and the certainty of the type sections of the unconformity at the base of the Kolhan must always be kept in mind. However, the point I would emphasise is that faulted areas of Kolhan phyllites, indistinguishable from Iron-ore phyllites, are probably more prevalent than the maps indicate.

Notwithstanding these new facts it is true that Iron-ore Series phyllites are extensive in area and in thickness between Noamundi and the Iron-ore Range. We must consider the stratigraphical position of these phyllites of the central area. The paucity of phyllites on the eastern side of the banded-hematite-quartzite extending south from Noamundi—and few of these are true phyllites—is in remarkable contrast to the very widespread phyllites in the centre of the horseshoe. This at once would suggest that the phyllites on either side of the banded-hematite-quartzite of the east rim belong to entirely different zones.



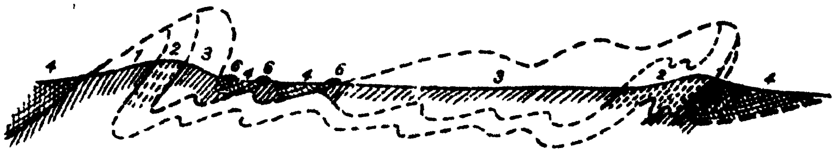
(*a*)

Section (a). *1—Lower lava. 2—Lower phyllite and tuff. 3—Banded-hematite-quartzite. 4—Upper phyllite and tuff. 5—Upper lava. 6—Kolhan Series outliers.*



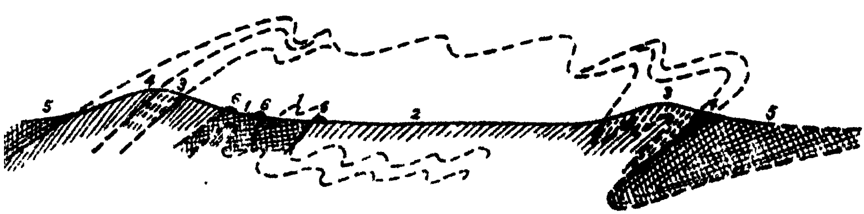
(*b*)

Section (b). *1—Lava. 2—Phyllite and tuff. 3—Banded-hematite-quartzite. 4—Upper phyllite and tuff. 5—Kolhan Series.*



(*c*)

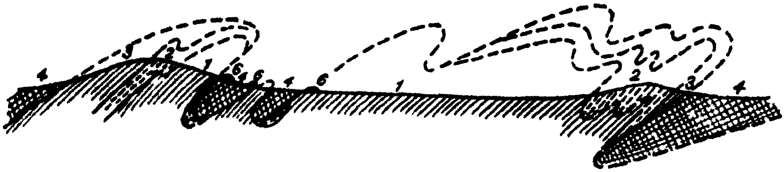
Section (c). *1—Lower phyllite. 2—Banded-hematite-quartzite. 3—Upper phyllite. 4—Lava and tuff. 6—Kolhan Series.*



(*d*)

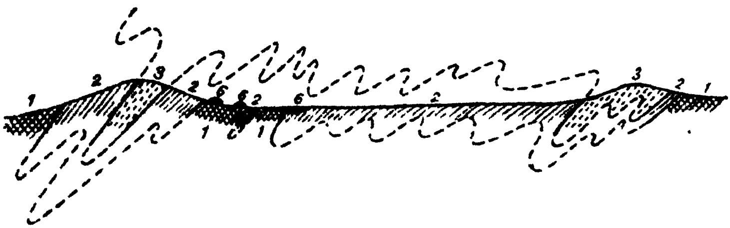
Section (d). *1—Lower lava and tuff. 2—Lower phyllite. 3—Banded-hematite-quartzite. 4—Upper phyllite. 5—Upper lava and tuff. 6—Kolhan Series.*

Fig. 3.—Alternative sections across the Iron-ore Series (*contd.*).



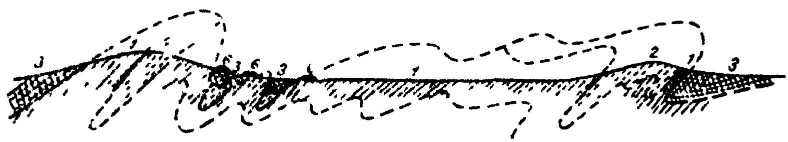
(e)

Section (e). *1—Lower phyllite. 2—Banded-hematite-quartzite. 3—Upper phyllite. 4—Lava and tuff. 6—Kolhan Series.*



(f)

Section (f). *1—Lava. 2—Phyllite and tuff. 3—Banded-hematite-quartzite. 6— Kolhan Series.*



(g)

Section (g). *1—Phyllite. 2—Banded-hematite-quartzite. 3—Lava and tuff. 6—Kolhan Series.*

FIG. 3.—Alternative sections across the Iron-ore Series.

I have heard it contended that there cannot be any phyllites overlying the banded-hematite-quartzites in Singhbhum as the latter invariably occupy the hill-tops and phyllites the valleys. In view of the known overfolding prevalent in places, the basis of this contention has no significance by itself.

There is at least one place where phyllites are clearly seen to overlie banded-hematite-quartzite. About 1¼ miles east of Bonoikora (22° 02′, 85° 26′), the Kundra *nadi* has cut a gorge through the banded-hematite-quartzite, which is here only about 100 feet thick and dips west at a shallow angle, 20°-30°. On its eastern side a narrow zone of phyllite, between the lava and the banded-hematite-quartzite, dips below the latter. On the western side, phyllites are seen to overlie the quartzite conformably, and in the latter there is no sign of close synclinal folding, and no lavas are exposed further west. The sequence may, of course, be inverted.

In the mine quarry faces occasional phyllites are seen to be interbedded with the banded-hematite-quartzite, such phyllites sometimes grade to ore. In the wide area of massive cherts north of Jamda, phyllites are also interbedded, and cherts are interbedded with the wider areas of phyllites.

Although, as indicated in the Kundra *nadi* section, some phyllites must overlie the banded-hematite-quartzites besides being interbedded with them, the lavas, tuffs and associated phyllites between Noamundi and the Iron-ore Range cannot be accepted with certainty as stratigraphically overlying the banded-hematite-quartzites. There is no direct evidence of their position in this locality, especially in view of the known overfolding.

Bearing in mind the above alternatives, seven sections can be drawn across the horseshoe from west of the Iron-ore Range across to the eastern side of the Noamundi ridge, each section conforming to the known outcrops—fig. 3.

Section (*a*) is of a simple geosyncline, the sequence in ascending order being: lava, phyllite, banded-hematite-quartzite, phyllite, lava. This requires two periods of thick lava flows, but, as pointed out earlier, the evidence would suggest that the wider areas of flows in the centre of the horseshoe are to be correlated with the flows around the rim.

Section (*b*) is of a geosyncline within which inliers of the lava have been brought up by minor anticlines. The sequence from the base is: lava, phyllites (impersistent, but thickening particularly to the north-west), banded-hematite-quartzite, phyllites (main group).

Section (*c*) is again of a geosyncline with the following sequence in ascending order: phyllites, banded-hematite-quartzite, phyllites,

lava. In this case, however, the discordance between the lava and the banded-hematite-quartzite would be of the nature of a major unconformity, far greater than the evidence would indicate, comparable in fact to the unconformity between the Kolhan Series and the Iron-ore Series. But, as has been already remarked, the very manner in which the Kolhan Series cuts right across the strike of the lavas and banded-hematite-quartzite north of Noamundi mine, and the general parallelism of the two latter, indicates the relatively close relation of the lavas to the banded-hematite-quartzite group.

Section (*d*) is of a simple geoanticline with the upper lava showing overlap. The sequence, ascending, is: lava, phyllites, banded-hematite-quartzite, phyllites, lava. For the same reason as given under section (*a*), that is, the postulation of two main groups of lava, this section is not favoured.

Section (*e*) avoids the objections to the last section, and the sequence becomes simplified, in ascending order, to: phyllites, banded-hematite-quartzite, phyllites (impersistent), lava.

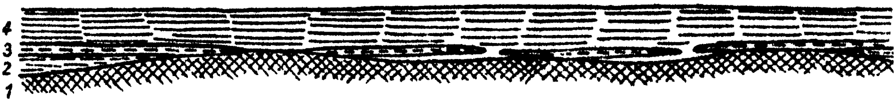
Section (*f*) introduces additional structures—synclines of banded-hematite-quartzite on either side of a major geoanticline. In this the ascending sequence would be simple: lava, phyllites, banded-hematite-quartzite. The single phyllite stage would show remarkably rapid variations in thickness.

Section (*g*) retains the structure of the phyllites and the banded-hematite-quartzites of section (*f*) but superposes a further wider geoanticlinal structure in which later lavas take part. This section carries the same objections as in section (*c*).

Although all of these sections remain possibilities, the truth is more likely to be found amongst sections (*b*), (*e*) and (*f*). The sequences pictured for each of these sections are illustrated in fig. 4.

In section (*b*) the banded-hematite-quartzite, interbedded with the phyllites, is shown as thinning out in places, and sometimes resting directly upon the uneven lava surface.

In section (*e*) the banded-hematite-quartzite has been gently folded or warped, with erosion of some of the beds before the lavas were extruded.

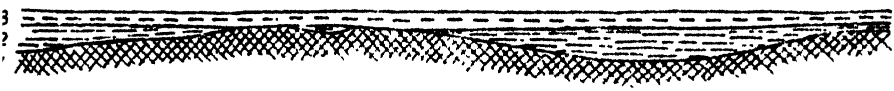


(b)

Section (b). *1—Lava. 2—Phyllite and tuff. 3—Banded-hematite-quartzite. 4—Upper phyllite and tuff.*

(e)

Section (e). *1—Lower phyllite. 2—Banded-hematite-quartzite. 3—Upper phyllite. 4—Lava and tuff.*



(f)

Section (f). *1—Lava. 2—Phyllite and tuff. 3—Banded-hematite-quartzite.*

FIG. 4.—Alternative original sequences according to Fig. 3.

In section (*f*), the phyllites within the centre of the horseshoe represent a considerable rapid thickening of the phyllites which are known to occur between the lava and the banded-hematite-quartzite on either rim of the horseshoe. The contrast in thickness of the phyllites is most strongly shown on either side of the eastern rim, where over a distance of 25 miles along the strike there is only a very narrow and impersistent zone of phyllites to the east of the banded-hematite-quartzites, whilst across the strike of the latter (a distance of only one hundred yards in the Kundra *nadi* gorge east of Bonoikora) phyllites attain a considerable thickness. On the eastern side of Noamundi mine, there is no evidence of extensive faulting which would eliminate a great thickness of phyllites. Section (*f*) would, therefore, presuppose a considerable warping of the lava surface giving

rise to a deep basement within a short distance to the north-west, in which a greater thickness of sedimentary material accumulated. A similar explanation would be necessary for the rapid widening, in a northerly direction, of the zone of phyllites along the western rim of the horseshoe, unless faulting is an alternative there.

The most favoured choice seems to lie between sections (*b*) and (*e*), of which the one is an inversion of the other. As has been noted the only exposures are along the eastern rim where, between the lavas and the banded-hematite-quartzite, there is an impersistent zone of tuffs, interbedded with altered lavas and usually altered to phyllites. For long distances this zone of tuffs is entirely absent. Usually the upper part of the lava was deeply oxidised in Iron-ore times and altered to red clay and chert, and, particularly further south in Keonjhar in the area recently mapped by Mr. B. C. Gupta, no clear-cut boundaries can be drawn between lavas, tuffs, and banded-hematite-quartzite. In Keonjhar a zone of indefinite lavas, tuffs, phyllites and cherts, between the normal lavas and banded-hematite-quartzite, attains an outcrop width of one mile. If the sequence along this eastern rim is normal, then the lavas were severely decomposed in the final stages, the previously noted conglomerate in the railway cutting north-east of Noamundi mine representing a local washout at the base of the tuffs. The tuffs, at the top, contain interbedded cherts which higher still give place to massive banded-hematite-quartzite, followed finally by phyllites.

If the sequence is inverted along this eastern rim, then the main phyllites gave place to banded-hematite-quartzite which merges upwards to interbedded tuffs and cherts and thence to lava, the conglomerate north-east of Noamundi mine representing a washout at the base of the lava. Also the tuffs and early lavas would have been severely decomposed and altered to hematite before the final outburst of lava.

This decomposition of the lavas and tuffs to hematitic material along the contact of the banded-hematite-quartzite (which finds a parallel also along the base of the later Kolhan Series), the absence of banded-hematite-quartzite pebbles in the interbedded conglomerate north-east of Noamundi mine, and the gradation of each group—lavas to tuffs and tuffs to banded-hematite-quartzites—would, perhaps, favour a normal sequence along the east rim as in section (*b*). Further, we know that severity of folding and overfolding increases westward, and the disposition of the banded-hematite-

quartzite around the horseshoe fold, with wide outcrops on the eastern and narrow outcrops on the western sides, would suggest that the sequence is normal on the east and inverted on the west. In addition, the folding of the synclinal basin of the later Kolhan Series suggests a continuation of pre-Kolhan synclinal fold movements, but displaced slightly east (as would be expected with the tendency to overfolding on the western side).

One of the pleas in favour of section (*e*) is that, in the centre of the horseshoe, the banded-hematite-quartzite occupies the tops of the hills, with phyllites in the slopes and valleys. Although apposite evidence, it has been remarked already that in an area of widespread overfolding it cannot be accepted without other support.

It is natural that we should look to adjacent areas in Singhbhum in the hope of finding some clue to the true sequence. If the lavas are at the top of the sequence they are comparable to the position of the Dalma lavas in North Singhbhum. On the other hand, if the lavas are at the base they are comparable in position to the wide area of basic igneous rocks which clearly underlie the banded-hematite-quartzites in South Dhalbhum, although in the latter locality much of the basic rock is intrusive. It may be remarked that the Dalma lavas provide the closest comparison in rock type.

Appreciating the difficulties in this region of close overfolding, in which actual rock contacts are rarely seen, as so much is covered by thick alluvium, hill debris and dense jungle, it is difficult to come to any definite conclusion. Further work to the south will, it is hoped, solve the problem.

The lavas.

East of the banded-hematite-quartzite of Noamundi.

The large area of lava extending south from the western half of sheet No. 73 F/12, east of Noamundi mine, apparently consists of a number of flows. It often has a bedded appearance and is typically amygdaloidal. The bedded lavas are sometimes seen to be gently folded, but structural evidence is normally lacking. Towards the eastern boundary shearing becomes noticeable, and it is into this sheared area that the granite has been intruded.

Microscopically the lava usually consists of small augite crystals in an extremely fine groundmass, which may show a fine radiating structure and represents a devitrified glass. The centres of the

majority of the augite crystals are altered to chlorite. An analysis of such a rock, 54/441, containing a few amygdules of silica, is given in Table 1, page 329. Sometimes, a felted groundmass of needles of altered felspar in devitrified glass may contain a few phenocrysts of chlorite and quartz which were possibly originally felspar. At times the texture is trachytic. Where coarser grained, felspar and augite show a typical ophitic structure, but the augite is frequently altered to chlorite and epidote. Fine magnetite and leucoxene are often present. The amygdules are variable. Some are entirely of fine chert, others of coarser quartz with a thin rim of chert or fine chlorite, others again of chert and epidote, or of radiating zeolites altered to epidote and surrounded by chert, or of chlorite edged by prisms or fine grains of epidote, whilst occasional amygdules may show a stratified structure of chert and zoisite in one half, the remainder being infilled with quartz. With recrystallisation, the chert gives place to coarser quartz.

Specimens may be collected which are so full of amygdules that the lava groundmass is a minimum. These have been altered more readily than the less amygdaloidal material and the glassy groundmass is now usually represented by hematite in which little rounded and lath-shaped areas of quartz presumably represent original augite and felspar respectively. Sometimes the highly amygdaloidal lavas are now altered to rounded areas of white quartz in a limonitic groundmass. It is also noticeable that the more amygdaloidal lavas have been more liable to silicification than the normal lava. Such silicification appears to extend outwards from the amygdules and when complete the rock is altered to a massive chert or jasper.

Between Kotgarh and Noamundi mine deep oxidation and decomposition of the old lava surface below the base of the Kolhan Series is persistent. Almost everywhere along its border here, and to the south along the edge of the banded-hematite-quartzite, the lava has been altered to hematite-rock, or to a hematitic argillaceous material which, with movement, has given rise to a hematite phyllite. In this altered rock the amygdules of the ancient lava are often still preserved. Other material associated with it appears to be the alteration product of fine tuffs; it is not possible to be certain whether some of the highly oxidised rock is altered tuff or altered lava. This is particularly so in the railway cutting north-east of Noamundi mine. Silicification of this surface rock was

frequent and gave rise to white chert, and to red, green and mottled jaspers, which are commonly found immediately below the Kolhan conglomerate. Frequently the alteration was such as to produce an iron-ore of hard hematite. It is apparent that this alteration was, at least in part, of sub-aerial origin in Kolhan times, but the fact that similar alteration has taken place in the lava immediately below the banded-hematite-quartzite suggests that there was contemporaneous oxidation also in Iron-ore times.

Although tuffs intervene between the lava and banded-hematite-quartzite at Noamundi ridge, the lava undoubtedly immediately underlies the hematite-quartzite in many places. An excellent example of this is on the ridge north-west of Churia Pahar (22° 01′, 85° 28′), where oxidised amygdaloidal lava is in juxtaposition to hematite-quartzite, which, at the actual contact, is often a mottled jasper or chert rather than the fine-banded type. At this point the abundant amygdules are beautifully preserved in the hematitised lava, which is occasionally sheared and grades to a phyllitic hematite-rock, in fact at times it could only be called a hematite-phyllite. Wherever hematite-phyllites occur along this boundary, unless their fragmental nature clearly indicates that they are tuffs, there is always the probability that they are sheared altered lavas. That movement has taken place along the boundary between the banded-hematite-quartzite and the lava is obvious, as it has taken place throughout all of these South Singhbhum rocks, and probably part of the boundary is a fault but, to date, there is no evidence of profound overthrusting along this edge of the horseshoe fold.

Occasionally, within the large area of lava, small outcrops of silicified tuffs are found. These may consist of angular fragments of ferruginous material, some, containing small amygdules, apparently after lava, other fragments are of quartz or chert, and the matrix consists of fine ferruginous chert in which incipient fine needles of an undetermined yellow mineral may occur.

Shearing of the unoxidised lava gives rise to a chlorite-schist which may often have a phyllitic texture. Such shearing is more prevalent towards its eastern edge.

The intrusive relation of the Singhbhum granite into the main area of lava may be seen in the *nadi* to the south of Bara Nanda (22° 13′, 85° 38′), at many places north-east of Bhondgaon (22° 05′, 85° 35′), in the small *nadi* north-west of Kondra (22° 03′, 85° 31′) where it intrudes between the sheared lava and quartz-schist, and

in the Kondra *nadi* south-west of Kondra, where hybrids have been formed. There are, of course, innumerable examples of this intrusive relation of the granite in the epidiorites and hornblende-schists between Jagannathpur and Chaibasa.

Metamorphism of the lava commences close to its contact with the Singhbhum granite, especially to the east of Bhondgaon (22° 05′, 85° 35′) where a large area of lava, both sheared and undisturbed, is swarming with intrusions of granite, pegmatite and quartz-veins. Most of this country is covered, but granite is associated with almost every outcrop of epidiorite and hornblende-schist, and it is difficult to say whether granite or metamorphosed lava is the more abundant. This was the area which was previously mapped as Older Metamorphic Series, the actual boundary between this and the unaltered lava (originally regarded as a sill) being taken along the foot of the hills. Recent careful examination has shown that there is no justification for this separation, and there is, in fact, no boundary. Typical unaltered lavas, often amygdaloidal, are quite commonly found as much as 1½ miles outside of the old boundary, and it may be noticed how rapidly these grade to epidiorite and hornblende-schist and even hybrids where there is granite. In this area phyllites are also interbedded with the lava, and they become metamorphosed to sericite-quartz-schists and mica-schists, which also form hybrids with the granite. Possibly some of these phyllites are really sheared altered lavas, similar to the phyllites after lava along the banded-hematite-quartzite boundary and below the Kolhan conglomerate; in fact, in sections along the streams here, there appear to be gradations from lava to phyllite.

In the early stages of metamorphism, the ophitic texture of the lava is well preserved by the felspars, but the original augite is altered to fine hornblende, with sometimes diopside. Epidote also becomes rather abundant, with also chlorite. Amygdules may still be determinable. With increased metamorphism the felspars disappear, the fine ophitic structure is lost and the hornblende forms quite well-developed crystals associated with quartz. Where schistose, the rock is, of course, a hornblende-schist. Diopside may be quite abundantly and coarsely developed where the basic rock is included in granite. A hybrid, associated with granite to the west of Daobera (22° 07′, 85° 38′), consists mainly of hornblende, diopside and some chlorite in a finely granitic or ophitic matrix which is now rather sericitised and contains sphene, zoisite and a

brownish chloritic material. Some calcite is present near the diopside.

Associated with the same granite, west of Daobera, there is also a hybrid of granite and mica-schist. The granitic part of the rock is of rather fine-grained quartz and orthoclase with a little plagioclase, apatite, rutile and the brownish chloritic mineral, and in this there are patches of coarse muscovite and abundant brown tourmaline. A little chlorite and magnetite are also present.

The metamorphosed basic igneous rocks with, in places, associated banded quartzites, which are found in the granite below the base of the Kolhan Series between Jagannathpur and Chaibasa, are now believed to be Iron-ore Series rocks. There is no reason for regarding them as a separate series, they are lithologically identical in every respect with the rocks in the adjacent main Iron-ore Series area, except for a rather higher degree of metamorphism, and the association of hybrids with the granite. But this metamorphism and hybridisation, we have already seen, takes place also where the main area of the Iron-ore Series has been intruded by granite.

These metamorphic rocks have been already described by Jones, but I will take this opportunity of describing here the interesting schists along the Deo *nadi*, below the Kolhan conglomerate. There is a remarkably clear exposure, in the stream bed, of inclusions of banded-hematite-quartzite and basic igneous rock in the granite. On the north-east bank of the stream a bed of banded-hematite-quartzite dips north-west at 40°, below hornblende-schist and hematite-schist. In places the latter are stained a bright green along the cleavage and surface, possibly a copper staining. In the bed of the stream the hematite-quartzite breaks up into small blocks in the granite, the blocks retaining usually the general strike of the larger bed. As a rule the quartzite blocks have quite sharp boundaries against the granite. The banded-hematite-quartzite has been recrystallised by the granite, the cherty texture is destroyed, and the quartz is sugary. The hornblende-schist has also broken up in the granite, but the blocks still retain the general strike. Their edges, however, are not always clear cut, hybridisation having taken place with the granite magma. Prior to intrusion by the granite, the basic igneous rock had been largely altered to carbonate rock and to hematite-schist. The more normal hornblende-schist under the microscope consists of hornblende and chlorite with a

little carbonate and quartz, and patches of fine hematite. This grades to a rock consisting of chlorite with some fine quartz and carbonate which may grade further to a rock consisting almost entirely of carbonate with some chlorite. In some inclusions the chloritic content has been oxidised, in places, to hematite and these may grade to a hematite-sericite-schist. The latter consists of a groundfabric of fine sericite and hematite in which are occasional flakes of muscovite, partially hematitised, and much irregular quartz, fine leucoxene being often present also. These sericite-schists have a bright green colour where not deeply stained by hematite. The muscovite is apparently due to recrystallisation of the sericite. On granitisation of these schists, coarse quartz and felspar develop within them, but the felspar has been later sericitised or partially replaced by hematite. Apatite grains are common in the hybrids.

It is apparent that the basic igneous rock was in part altered to hematite-chlorite-sericite-schist, and to carbonate-rock before intrusion by the granite. The alteration to hematite-chlorite-sericite-schist is exactly similar to that which has been noted to have taken place at the top of the lava east of the Noamundi ridge, the only difference along the Deo *nadi* being that the granite has caused some recrystallisation.

Around Nurda (22° 20′, 85° 44′) the basic igneous rock is altered to talc-rock and sometimes to talc-schist. Talc-rock, chloritic talc-schists and sericite-schists after lava also occur below the Kolhan rocks around Chaibasa. The rocks here usually consist of fine sericite with abundant leucoxene, in which coarser flakes of muscovite are largely replaced by hematite. Where closely penetrated by granite, large angular grains of quartz appear in this rock, which show partial replacement by sericite, and these grains may be so abundant that it becomes a quartz-sericite-rock. Below the Kolhan conglomerate the granite also becomes sericitised to quartz-sericite-rock, and it is not easy in the field to judge whether some of these rocks were granite or slightly hybridised altered basic igneous rocks.

About 1¼ miles north-east of Chaibasa the typical amygdaloidal lava crops out. Some was originally glassy, but is now altered to a dark brown material full of fine magnetite and containing abundant amygdules of chert with coarser centres and a chloritic lining. Some has an ophitic texture, but the augites are chloritised, felspars altered and carbonate is abundant. In places the lava picked up angular fragments of quartz and chert. Associated tuffs contain

irregular fragments of chlorite, quartz, chert and slaty fragments, in a chlorite matrix.

Between Barabil and Gua.

The lavas cropping out between Barabil and Gua are closely folded and contain thin interbedded phyllites. Sometimes, as in the larger outcrop one mile west of Uliburu (22° 08′, 85° 23′), amygdules are abundant; this outcrop, particularly on its western side, is altered to a limonitic material in which the white amygdules stand out in contrast. Many of the outcrops are of quite fresh massive lavas, others are highly sheared to chlorite-schists and to the north they may be well-cleaved hornblende-schists, but a large proportion of the outcrops are of hematitised lavas or even iron-ores, or sericite-rocks and talc-rocks, in some of which amygdules may still be seen. Alteration to clay is common. Particularly in the hills between Bokna, Gua, the Karo River and the railway line, the lavas are so altered and so closely associated with phyllitic tuffs and normal phyllites that the mapping can be only diagrammatic. As shown on the map, the lava areas represent areas in which lava predominates and in the phyllite areas phyllite is the more abundant. The alteration of the lava is similar to that which has been described in the larger area east of Noamundi mine.

The lava sometimes shows ophitic structure, with abundant felspars in augite, the latter being partly chloritised. In other cases small prisms of zoned augite (with chloritised centres) occur in a fine devitrified matrix which may contain much epidote. Amygdules are of fine quartz, chlorite and altered zeolites, which may have a rim of zoisite, chlorite, calcite or altered zeolites.

To the south of Jhiling Buru, east of the road and extending to the river, some of the lava has an unusual structure, which, from the hand specimen, may be described as spherulitic or even orbicular, as on the weathered surface it is seen to be made up of little spheres, up to 1 inch across and often touching. Under the microscope the spheres are seen to consist of small augite prisms in an extremely fine radiating groundmass of devitrified glass. The outer zone or matrix is more crystalline with more augite and microlites. Some epidote and quartz are present and thin chert veins traverse the section. All the augites are zoned and the centres altered to chlorite. An analysis of this rock, 54/463, is given in Table 1. The more normal lava is similar to the matrix of the above

rock, and it will be noticed that this is identical with much of the lava east of the Noamundi mine.

The lava just described underlies the conglomerate at the south-east end of Jhiling Buru. Immediately below the conglomerate the lava has been altered to a structureless argillaceous material, at times a white clay, at others it is iron-stained. Under the microscope little plates of muscovite are found to be scattered throughout. Such muscovite is also found in a phyllite which occurs as a thin bed within the lava.

The great majority of these outcrops are of fine-grained lava. There are, however, certain rather coarser but medium-grained doleritic rocks, dyke or sill-like in outcrop, such as the one a mile north-west of Diriburu (22° 12′, 85° 25′), which may be intrusive. Indeed, it is not unlikely that some of these probable intrusives may be Newer Dolerite in age. Cropping out in the Karo river, on the northern side of the conglomerate which overlies the spherulitic lava described above, there is an ophitic dolerite, 54/462, an analysis of which is given in Table 1. This may be either a flow or a later intrusive.

TABLE 1.

—	54/441 Lava N. W. of Ichakuti.	54/463 Lava 1½ miles S. of Gua.	54/462 Dolerite 1 mile S. of Gua.
SiO_2	55·80	53·20	48·88
Al_2O_3	12·37	9·73	10·61
Fe_2O_3	2·20	3·94	1·57
FeO	7·93	9·92	11·05
CaO	5·90	6·77	6·60
MgO	8·93	9·58	12·88
MnO	0·22	0·18	0·24
K_2O	1·50	1·06	0·58
Na_2O	1·10	1·24	1·86
P_2O_5	0·01	0·08	0·01
TiO_2	0·60	0·83	1·60
H_2O-	0·30	0·40	0·42
H_2O+	3·10	3·10	3·58
S.	0·05	0·01	0·13
TOTAL	100·01	100·04	100·01
Sp. Gr.	2·864	2·993	2·948

Analyst—R. Dutta Roy.

The undoubted lavas between Barabil and Gua are indistinguishable, petrologically, from those to the east of Noamundi mine. The curious radiating devitrified groundmass, in which small zoned prisms of augite are scattered, is a typical feature of both areas. In addition, the alteration to hematite-sericite-rock and hematitic schists, and even to iron-ore, is common.

The phyllites and tuffs.

East of the banded-hematite-quartzite of Noamundi.

Between the lava and the banded-hematite-quartzite of Noamundi east ridge there is a zone of tuffs which were called by Percival the "Mohudi shales". This was previously a useful term, but it seems no longer necessary to retain it. Percival recognised that they were not normal shales and that they were, in fact, altered tuffs. In addition, quite a considerable amount of altered lava is interbedded.

I have found it difficult to determine a junction between the main lavas and tuffs. Both are so highly altered to a similar hematitic argillaceous material that any boundary has been obscured. However, at the west end of the railway cutting immediately south of Sangramsai village there is a peculiar conglomerate which may be taken to represent the base of the tuffs at this point. To the east the altered lavas dip westward at about 30° below the conglomerate, which retains the same dip below a similarly altered material, which may be tuff or lava, further west.

This conglomerate is unusual. It consists of pebbles, up to 6 inches across, of quartz and quartzite, and some of altered lava, in a matrix which is indistinguishable from the altered lava or tuff. The pebbles are mostly water-worn, and often have an iron-stained surface. The quartzite pebbles consist of silicified rounded quartz grains with small rounded patches of sericite, and with a little interstitial hematite. The conglomerate presumably represents a contemporaneous wash derived partly from the old lava surface, and partly from some still older rocks. This evidence, that on older series of sedimentary quartzites existed in the neighbourhood below the lavas, is important.

That some of the material interbedded with the tuffs is altered lava is illustrated by microscopic examination. Usually it is a structureless argillaceous material, much altered to sericite, and containing ramifying veinlets of hematite and sometimes of clay, and

occasionally a little secondary quartz, but in places the fine hematite and sericite have retained the curious fine radiating structure so typical of the adjacent lava. Sometimes also the sericite retains the lath-shape of original felspars.

Usually, west of Sangramsai, these altered rocks are massive, with little sign of bedding, but jointing and often cleavage may be well-developed in them. Sometimes they have been leached almost white in colour, or they may be mottled red and white, thus grading to the more normal red colour. At times, however, they show banding and so grade to the typical "Mohudi shales" of Percival on Noamundi east ridge. I have seen colour banding in only partially altered lava on the eastern side of Noamundi ridge.

Percival has already described in detail the "shales" or tuffs of Noamundi east ridge. Usually they are soft, mottled and banded argillaceous rocks which have been considerably leached and replaced. The less altered rock is somewhat cherty in appearance, or rather, might be compared with an extremely fine grey-white sandstone with greenish tinge. The irregular staining of this material by hematite has given rise to a mottled colouring. A faint fine banding, presumably bedding, occasionally noticeable in the original rock, has been followed by the replacing solutions, thus giving rise to the alternating red and white "shales", but sometimes a second banding cuts across this. Much of the rock is so completely replaced as to form a soft laminated ore, especially on the north-east side of the ridge. Such ore breaks up into close-jointed fragments which can be fairly readily separated from the associated clay. Sometimes the banded red and white clay is traversed by innumerable fine ramifying veinlets of white clay.

Under the microscope the unaltered fine tuff is seen to consist of small fragments of quartz and chert in a sericitic and cherty matrix. Although no grains of iron-ore are observable, there are many fine grains of what appears to be leucoxene. In the early stages of the introduction of hematite, there is a patchy replacement of the matrix, producing the mottled "shales". With further alteration the whole rock may be altered to an argillaceous or sericitic material, deeply stained by hematite, in which only a few small quartz fragments may be left.

Towards the top of these tuffs, where they are also banded, they are irregularly silicified, forming a green and red chert in which there are patches of less siliceous unreplaced tuff. The siding

cutting on the north-west corner of the ridge, exposes the tuffs, cherts and banded-hematite-quartzites which form a conformable sequence dipping at 45° in a westerly direction. Immediately below the lowest chert band in the cutting there is a 6 inch zone containing flat lenticular fragments of altered tuff, which looks like an old surface. The overlying chert is banded and merges up the sequence into laminated ore which really forms the base of the banded-hematite-quartzite at this point. Apart from the finer banding in the banded-hematite-quartzite, it does not differ from the banded chert associated with tuffs immediately below it, and there is no sharp dividing line.

On the eastern side of the ridge the tuffs are finer banded and dips flatten to only 10° west, in fact horizontal bedding was noticed locally in the workings where the beds were being rapidly quarried.

Further south, ferruginous phyllites may be traced along the base of the banded quartzite in places, but for long distances the lavas appear to directly underlie the quartzite, and usually the top of the lava is highly altered. In many places such altered lava, with development of cleavage, grades to ferruginous phyllite in which drawn-out amygdules may be seen at times, as on the north-east side of Churia Pahar (22° 01′, 85° 28′). At Inganjoran the "phyllite" is hard and dense, red on the surface, but green on the fresh fracture; its cleavage is vertical and slickensided close to the Kolhan sandstone boundary, which is here undoubtedly a fault.

Between Noamundi and Gua.

In the accompanying map, the old boundaries between the phyllites and banded-hematite-quartzite west of Noamundi, as shown on Jones's map, have been retained. Hill-side debris is deep and the jungle thick, so that the boundaries can only be mapped approximately, except where mapped in mine workings.

These phyllites have, in the past, been referred to as "shales". I have nowhere seen a normal shale amongst them. On the weathered surface they may sometimes appear to be shaly, but a well-developed slaty cleavage and usually a fine phyllitic sheen is developed wherever fresh. Sometimes two or more cleavages have even developed in them. Bedding is rarely observed and almost all the dips recorded are cleavage dips. Close folding cannot, as a rule, be detected in outcrops of these phyllites, as cleavage suppresses all other structure, but in rail and quarry cuttings there is abundant

evidence of the close folding and faulting to which these rocks have been subjected. Perhaps the best sections are to be found along the road cuttings ascending to the mine above Gua, where the finely banded phyllites can be followed in all their contortions even though the close cleavage cuts across the bedding. In road cuttings about 2 miles south of Gua, close recumbent folds in the phyllites are at so flat an angle that, if not seen in section, they would be regarded as normally horizontal. Crush zones are also seen occasionally, as in the cuttings at the bottom of the old incline at Gua.

Although ferruginous purple phyllites are the most abundant, buff, white, grey, green and even black phyllites are quite common, and occasionally they are mottled. Although usually fine-grained, beds of quite coarsely fragmental material—still phyllitic—occur in them and these are obviously tuffs.

For the most part cleavage lines trend N.E.-S.W., but there are many local divergent strikes. Quite frequently, close to the base of the Kolhan conglomerate, the dips of the phyllite may be apparently conformable below the conglomerate, in consequence of the strong post-Kolhan folding which was superimposed upon the earlier folding. In the railway cutting north of Noamundi village, the phyllites have been dragged down along the unconformity below the Kolhan conglomerate as a result of the later folding (fig. 7).

Cherts are sometimes interbedded with the phyllites, and phyllites are interbedded with the wider areas of chert and banded quartzite. It has been remarked already that a large part of the area coloured as "shale" on the older map is deeply covered with alluvium or laterite, and that in all probability lavas and cherts are more abundant than appears from the map.

The phyllites are commonly manganiferous. This is well illustrated in some folded phyllites exposed in road cuttings about two miles south of Gua. Leaching of these rocks has given rise to enriched zones of nodular psilomelane and pyrolusite in the phyllites, or of lateritic manganese at the surface—there are apparent gradations between the two types of occurrence. In addition detrital material shed from these deposits has also been mined.

There are at least four belts along which manganese has been mined within the area re-surveyed. The most westerly commences on the western side of the Jhiling Buru mine south of Gua, extends south along the eastern side of the Iron-ore Range, and

follows the western side of the conglomerate bed across the river. A small belt occurs in the phyllites west of Uliburu. The next belt commences at about one mile north of Diriburu, with a blank interval to Noagaon, south of which many deposits have been worked through Nalda and to the south. The fourth belt commences in the hills north-east of Jamda village and extends S.S.E. towards Bilkundi.

Petrologically the normal phyllites are sericitic slaty rocks often containing a little fine quartz and with varying amounts of fine hematite. The tuff-phyllites are much more variable, however. These are well-developed around Gua. In the hand specimen they are all obviously fragmental rocks, the fragments being up to ½-inch across, but all closely cleaved. In the cutting below the ore-bins at Gua station, the tuffs consist of fragments of fine chloritic material, chert and a few grains of quartz in a chloritic and argillaceous groundfabric. Sometimes magnetite is quite abundant, and occasionally small flakes of muscovite have developed in the groundfabric.

In the bank of the Karo river, east of Gua, there is a good exposure of tuff. The fragments are of chert, hematitic chert, chlorite, sericite-schist, black slate, chlorite-schist and magnetite (altered mainly to hematite), which are in a matrix of chlorite and calcite. The fragments have been rather squeezed out by pressure, and are partly replaced by calcite. In some of the tuffs elsewhere, fragments of altered amygdaloidal lava have been seen. In rare instances the tuff is uncleaved and massive; about half a mile west of Jamda station, and also in the stream to the south-west, there is an instance of a tuff resembling a sandstone. It consists of angular fragments of chert and other material, altered to hematite, in a hematite matrix.

The cherts and jaspers.

That cherty rocks, apart from the banded-hematite-quartzites, are of widespread occurrence in the Iron-ore Series will have been gathered from the previous pages. These cherts are associated variously with the extensive outcrops of lava east of Noamundi mine, with the phyllites along the eastern side of the banded-hematite-quartzites extending south from Noamundi mine, and with the phyllites between Noamundi and Gua.

Thin bands of chert, or silicified tuffs, are occasionally seen within the lavas east of Noamundi mine. The finely fragmental nature of these rocks may be noticed under the microscope. The jasper, which occasionally occurs at the surface of the lava immediately underlying the Kolhan conglomerate, is more extensive, however, and is apparently due to silicification of the altered lava. Such jaspers are red, green or mottled in colour. Within the Singhbhum granite the inclusions of chert and banded jaspers have been recrystallised, the quartz being more coarse-grained. Magnetite commonly takes the place of hematite.

The cherts and jaspers, which follow the eastern boundary of the banded-hematite-quartzite, are usually red or white in colour, or are often mottled, or even green at times. A coarse banding is sometimes noticed, but is more common in the cherts just below the banded-hematite-quartzite. Under the microscope the chert is seen to be extremely fine-grained with a few small grains of quartz, the red colour being due, of course, to hematite which replaces the chert. Occasional coarse fragments may be found in the chert matrix. The fact that some of these cherts, just below the base of the banded-hematite-quartzites, are interbedded with the tuffs might suggest that the cherts themselves were originally deposited as normal sediments. However, in the mine workings, there are many instances of irregular siliceous replacement of the tuffs, sometimes in quite small patches, to form cherts. It can be said with certainty that at least many of the cherts are silicified tuffs, but whether this silicification was contemporaneous or later is debateable. In my opinion the bulk of the evidence suggests that it was more or less contemporaneous with deposition of the beds.

Cherts are widespread between Noamundi and Gua, especially to the north-east of Jamda. Here they are almost exclusively white in colour, and form massive beds in which usually no banding can be detected. On the map the distribution of these has been generalised, there is often considerable hill debris and lateritic cover, and also a great deal of phyllite is undoubtedly interbedded. In such a succession of beds of phyllite and chert the latter resists weathering and thickly strews the hill-tops and slopes with debris.

On the western and northern sides of Jhiling Buru, the cherts are variegated or mottled in colour, red, white and even green and yellow. In places at the north end of the hill, instead of the more massive outcrops usual in this vicinity some cuttings have

opened up sericite-schists, showing two cleavages, in which there are lenses of chert. The massive cherts exposed in a road cutting here have been coarsely brecciated and re-silicified. Such brecciation is a common feature of the massive cherts almost wherever they occur in this area. It is suggested that the cherts, instead of yielding to folding, were thoroughly shattered by the fold movements and were re-silicified.

Along the east side of the ridge south of Nalda, manganese is associated with dolomite and cherty quartzite. The dolomite is also cherty in patches and is much recrystallised. In many of the cherts in Singhbhum the outlines of carbonate rhombohedra, now infilled with chert but lined with hematite, have been observed. There is the possibility that carbonate rocks were originally much more widespread but have been removed by solutions leaving only the associated chert. I have no definite opinions on this, but it would provide an alternative to the origin of the chert breccias suggested above, the brecciation being due to collapse after removal of the lime.

Manganese deposits are often associated with the cherts. Visitors, familiar with the South African manganese deposits, have compared these cherts with the "surface quartzites" of the South African deposits, remarking that the cherts would not persist in depth. This may be true of any particular mass of chert, because of its lenticular character, but it is not true of the cherts in general. They are clearly pre-Kolhan in age, as their pebbles make up the greater part of the Kolhan conglomerate, as for example on the north side of Jhiling Buru.

Experience has shown that the highest grade manganese deposits are associated with chert. It appears that the chert was more readily susceptible to complete replacement by manganese than was the phyllite.

The banded-hematite-quartzites and iron-ores, and their origin.

The banded-hematite-quartzites of Singhbhum and adjacent areas have been previously described in such detail that there is no need of repetition. It is unfortunate that such a cumbersome name has been given to them, even although locally it has been shortened to B. H. Q.; the term banded jasper would have been preferable, providing the recrystallised nature of the quartz in many places is remembered.

In the field all gradations can be seen between massive chert and jasper through coarse and fine-banded chert and jasper, to the normal fine, close-banded hematite-quartzite. Quite commonly, at the base, the latter grades to massive chert and jasper, and these occur also within the body of the banded quartzites. Just as the latter vary microscopically from fine chert to relatively coarse granular quartz, so also similar gradations in recrystallisation of the quartz in massive chert have been observed.

Within the zone of banded-hematite-quartzite occasional beds of phyllite can sometimes be seen in quarry faces, but they rarely appear in outcrop.

Close folding may be observed almost everywhere in these banded quartzites, and occasionally overfolding, as at Gua. Quite commonly the fine bands are minutely puckered, and, at first sight. it is difficult to appreciate how such minute folds could have been imparted to such a competent rock. However, its finely laminated character and its high hematite content is the probable explanation, for, under pressure, the ferruginous laminae would readily yield, the thin silica layers following suit.

Experience during the past few years in working the mine quarries has shown that the bulk of the iron-ore has been formed by enrichment within banded-hematite-quartzite, enrichment within phyllite being less important. This is particularly the case so far as hard massive ore is concerned. Irregular distribution of the ore is due almost entirely to irregularity in enrichment of the banded quartzite, and very rarely to faulting.

The origin of the banded-hematite-quartzites has been so frequently discussed previously that little need be said here. However, I should like to repeat the warning which I have made elsewhere,[1] that a common origin is not to be found for all banded hematite-quartzites throughout the world. The banded greenalite rocks of the Mesabi Range, U. S. A., are different in origin from the ribbon jaspers of the Gogebic Range, U. S. A. Within my own experience in various parts of Singhbhum, I have seen banded-hematite-quartzites, of similar appearance, derived by silicification of fine-banded oxidised hornblende-schists, ferruginous phyllites and tuffs, and recently of ferruginous fine Kolhan sandstones. I am prepared to admit that these more extensive banded

[1] J. A. Dunn, *Mem. Geol. Surv. Ind.*, 69 (1), pp. 208-9, (1936), and *Trans. Aust. Inst. Min. Met.*, 111, pp. 161-3, (1938).

hematite-quartzites in South Singhbhum may be original cherty sediments, but apart from their extensive character, I have seen no evidence contrary to the suggestion that they are silicified fine-banded oxidised tuffs.

Since the completion of the survey of the Iron-ore Series in North Singhbhum in 1926, I have persistently stressed the igneous character of the Iron-ore period there and in East Singhbhum. I was then under the impression that extrusive rocks were not so typical of the Series in South Singhbhum and Keonjhar. The recent re-survey has demonstrated that the extrusive igneous nature of much of this area had been overlooked and it is as characteristic here as in North and East Singhbhum. There is, in fact, nothing in South Singhbhum that is opposed to the views on the origin of these rocks built up from evidence accumulated in other parts of Singhbhum. As in these other parts, the tuffs and lavas were poured out largely under terrestrial conditions, oxidation was in progress accompanied by silicification of the oxidised rocks. Although hot waters were probably largely responsible for this silicification, neither the iron, nor the silica, nor the water were to any extent of direct magmatic origin. The waters were meteoric waters, heated by rising steam in this volcanic area, just exactly as are geyser waters in such thermal regions as Rotorua, Wairaki, or Yellowstone Park to-day. The iron was inherent in the tuffs, so also was the bulk of the silica in the adjacent rocks. The silica, leached from the underlying rocks by the heated meteoric waters, was deposited in tuffs and other sediments towards the surface, forming cherts which retained the banding of the original rocks. It is possible that the brecciated structure of some of the cherts arises from collapse over severely leached areas below.

Recognising the undoubted silicification which has taken place in this area, I no longer regard the extensive nature of the main banded-hematite-quartzites as being a barrier to regarding them also as a product of silicification. But yet, in a region of extensive lakes, it would still be possible for the circulating waters, emerging as lake-bed springs, to spread their burden of silica over the lake bottom, to be intermingled either with fine tuff or fine ferruginous wash from the shores.

Of the last hypothesis we have no evidence in Singhbhum; it remains an hypothesis the possibility of which cannot be denied. Evidence of silicification is so widespread, however, that we have

at least to admit the origin of many banded-hematite-quartzites from this cause—and such banded quartzites are formed by silicification of several different rock types.

Enrichment of iron both by desilication and by actual re-arrangement of Fe_2O_3 no doubt took place also at this stage to some extent. But it cannot be postulated that the "blue dust"—*i.e.*, fine incoherent hematite, varying to hematite-quartz powder, preserving all the fine banding of normal hard banded-hematite-quartzite with which it is associated—can have originated at this time. Such blue dust, or desilicated banded-hematite-quartzite, could never have retained its fine banding through all the close fold movements following not only the deposition of the Iron-ore Series, but also the Kolhan Series. At Gua, for example, there are excellent sections of blue

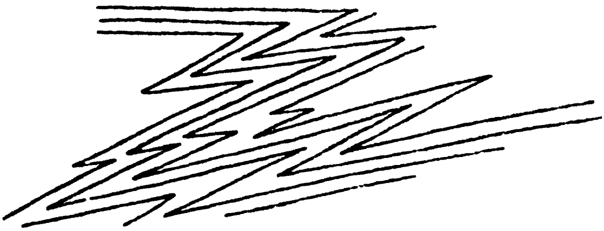


FIG. 5.—Sharp overfolding in "blue dust".

dust in which the fine-banding preserves all the delicate sharp horizontal recumbent folds of the original banded-hematite-quartzite, fig. 5. In one such section, between the thin layers of blue dust, there are thin layers of white, grey, buff and pink argillaceous material, which, on examination with a lens, is found to be closely slickensided not only along the bedding, but also acutely across it (fig. 6). Sometimes such thin clay layers are crossed diagonally by thin

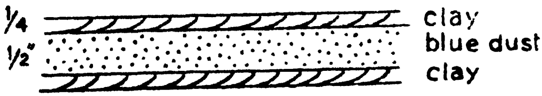


FIG. 6.—Slickensides in clay layers.

parallel veinlets of white clay. It is obvious that the whole material had been closely sheared during folding. The desilication which gave rise to the present "blue dust", must be at least post-Kolhan and is probably Recent in age.

From this conclusion it should not be interpreted that I believe the period of enrichment of Fe_2O_3 to form the iron-ore deposits was also Recent. Enrichment took place at any stage in the geological history of this area when conditions were suitable. Some of the iron-ore enrichment accompanied the silicification of the banded-hematite-quartzites. Further enrichment probably took place when the area was a land surface during Kolhan times. The Kolhan conglomerate contains iron-ore pebbles and it is even an iron-ore conglomerate at several points. That much of the enrichment is also Recent is shown by the frequent surface concentration of Fe_2O_3 as well as by the blue dust. Whenever and wherever these rocks were exposed at the surface, and subjected to circulating waters during their geological history, re-arrangement of Fe_2O_3 was in progress.

III. THE SINGHBHUM GRANITE.

The Singhbhum granite has been described previously in sufficient detail[1] so that no lengthy description is necessary here. I would, however, remark that gneissic banding, due to complete granitisation or absorption of schists of the Iron-ore Series, is more prevalent in South Singhbhum than elsewhere in this granite mass.

Although intrusive into the Iron-ore Series, all the evidence so far accumulated indicates that the Singhbhum granite, here in South Singhbhum, was pre-Kolhan in age, the basal beds of the latter being deposited on its denuded surface. This does not mean to say that no granite intruded into the Kolhan Series—so far as we know none did in South Singhbhum, but, in Dhalbhum, there is a group of rocks, known as the Dhanjori group, which, from one point of view, might be correlated with the Kolhan Series, and which is intruded by soda granite. However, I do not believe that, on the full evidence, a correlation between the Dhanjori and Kolhan rocks can be supported.

It is of interest to note that, occasionally, immediately below the Kolhan conglomerate, there is evidence of weathering of the granite during Kolhan times. The granite at these places grades to a sericite-quartz-rock, not unlike an arkose. The hybrids were also affected similarly.

[1] J. A. Dunn, *Mem. Geol. Surv. Ind.*, 54, (1929).
H. C. Jones, *Mem. Geol. Surv. Ind.*, 63 (2), (1934).

IV. THE KOLHAN SERIES.

The Kolhan basal sandstone-conglomerate.

THE MAIN BOUNDARY.

The description of the basal bed of the Kolhan Series may be conveniently commenced from Chaibasa. There are certain anomalies around Chaibasa which will be discussed later, but for the present the outcrops of purple sandstone, about which there is no doubt, will be traced.

The basal bed is clearly exposed in a railway cutting below the road, about one mile south of Chaibasa station. Here it consists of a fine-bedded flaggy sandstone, of purplish colour, resting unconformably on highly altered basic igneous rock, granite, and hybrid rock formed by the granitisation of the basic igneous rock. There is no sign that the granite intrudes into the sandstone, but on the contrary there is an old pebble surface, about 6 inches wide, between the two. The sandstone is more or less horizontal, with a tendency to dip west, but there are a few minor sharp folds, or puckers, with some faulting. From adjacent quarries it is evident that the basal bed on the eastern side of Chaibasa is at least 25 feet thick.

The purple sandstone here is typical of this rock throughout. It consists of rounded and sub-angular grains of quartz, felspar (orthoclase, microcline and plagioclase), fine chert and jasper, fine sericite, sometimes fine chlorite and talc rock, and occasional flakes of muscovite. The grains are not always of even size. Quartz is easily dominant and is usually strained. Felspars are often sericitised. Around each grain there is typically a rim of hematite, but later cementing quartz is usually in optical continuity with the quartz grains across the hematite rim. An argillaceous cement is rare.

The main boundary of the Kolhan Series can be followed south as a line of low sandstone ridges, raised slightly above the granite surface on the east and Kolhan shales on the west.

South-east of Kamarhatu the sandstone is manganiferous, altering to a manganiferous laterite, and along its upper surface, in the altered overlying rocks, deposits of manganese have been quarried. Similar deposits are found at Kelendeh and Kasia,

six miles south of Chaibasa. There are certain peculiarities about these deposits which will be discussed later (page 358.)

At Kelendeh a north-west striking fault off-sets the boundary. As exposed in some manganese quarries, the beds immediately along the walls of this fault dip steeply to the north-east. The continuation of this fault to the north-west can be seen in a railway cutting where the highly disturbed phyllitic shales contain innumerable veins and vughy spurs of white quartz.

At Tekorohatu the sandstone is very thin and Kolhan shales actually come in contact with underlying quartz-schist in a railway cutting. Although covering quite a wide area to the south, in consequence of its horizontal disposition, the sandstone is usually only a few feet thick, and frequently, as around the railway cutting east of Tutugutu, the granite peeps up from below it. The sandstone also appears to show a tendency to thin out to the west, and granite crops out at Tutugutu and Indkuri, both limestone and shale coming in contact with the granite. That this is not due to faulting is shown by the boundary around Bingtopang, where the sandstone-conglomerate thins out and the limestone rests directly on the granite.

Jones remarks that granite veins can be seen in the sandstone on the hillock just west of mile 6 on the Hat Gamaria road.[1] This hillock was carefully examined and granite veins in a hybrid rock were seen, but this latter rock is entirely different from the purple sandstone which overlies it on the main part of the ridge just to the west, and of which the hillock is the eastern end. The hybrid is similar to the hybrids which occur unconformably below the purple sandstone in the railway cutting at Chaibasa. No granite veins could be found in the purple sandstone.

South-west of Bingtopang the strike of the sandstone and overlying limestone becomes very regular. Dips vary from horizontal to 5° westward. Even here, where disturbance is at a minimum, quartz veins are abundant in sandstone, limestone and shale. Conglomerates are sometimes seen in the sandstone, as a rule at the extreme base. The pebbles in the conglomerate, as far as Kendposi, are usually of quartz, but jasper, banded hematite-quartzite, chert and sandstone-quartzite pebbles also occur. At one place, east of Indkuri, where an inlier of granite projects

[1] H. C. Jones, *loc. cit.*, p. 188.

above the limestone, a pavement of this conglomerate, consisting of 6-inch to 12-inch boulders of granite in a meagre sandstone matrix, is exposed.

Jones mentions that west of Simjang the granite has indurated and bleached the sandstone. I visited this section with Jones in 1922 and was jointly responsible for this interpretation. After further close examination I now do not regard it as providing the slightest evidence of intrusion by the granite, and with this view Dr. Heron and Dr. Fox, who recently visited this section with me, are in agreement. Such local bleaching and silicification is common enough in this basal sandstone either close to or away from the granite. The white rock differs only from the purple sandstone in that there is no hematite rim to the quartz, felspar, chert and other grains, and the quartz grains interlock. At this locality, a little debris of a peculiar dense grey chert overlies the sandstone; a very thin bed of similar chert overlies the sandstone west of Nurda. In both cases the chert contains a few angular quartz grains, some fine hematite and irregular patches of fine argillaceous material which the chert appears to have replaced. It is probably a replacement of limestone or shale.

South from Siringsia the Kolhan land surface was more irregular and the basal sandstone and limestone are absent for a space, the shales resting directly on granite or on hornblende-schists, epidiorites and banded-hematite-quartzites of the older rocks. Sometimes a conglomerate a few inches thick may be found. The Kolhan beds are perfectly horizontal and the thin basal sandstone west of Nurda forms quite a well-defined little scarp.

South of Nurda a much faulted and folded group of sandstones (with conglomerate) and shales extends east from the main boundary. This locality will be described later as there are certain anomalies associated with it.

South-west from Kendposi it is noticeable that, particularly at the base, massive white felspathic sandstones varying to arkose or conglomerate containing quartz and occasional jasper pebbles, now become associated with the purple sandstone. Outliers are found away from the main boundary, resting horizontally on granite, hornblende-schist or quartzite, and at times ridges of the latter project up through such sandstone or conglomerate. It is noticeable that the outliers further east are thicker and contain more of the white massive felspathic sandstone and conglomerate.

Along the Deo *nadi*, just north of Mungra village, is the section first found by Jones. Here, a thin bed of conglomerate, 12 inches to 2 feet in thickness, rests on the granitised schists of the older series and on recrystallised banded-hematite-quartzite. Overlying it just to the north, and dipping gently northwest, is a thin bed of shales followed by limestone. Following its strike south-westward the conglomerate may be found in the fields towards Baliadi, where it thickens somewhat for a short distance and dips to the north-west at 10°. South-west of Konslapos it rests on chert and granite, and, near the road, on granite which had been altered in Kolhan times and now resembles an arkose. A hybrid, with greenish tint, is also present, pebbles of which may be found in the conglomerate towards Konslapos. The conglomerate can be traced in the fields towards Bara Nanda.

I must here reply to verbal criticism which I have heard made on Jones's rock identifications west of Jagannathpur. Owing to unfortunate generalisation in the reduction of Jones's original maps from the 1-inch to the ¼-inch scale, there are places at which it would appear from the ¼-inch published map that Jones had mapped as sandstone certain peculiarly altered granites and hybrids beneath the basal bed. I am personally aware that Jones did recognise the igneous character of the underlying rocks and his original manuscript 1-inch maps demonstrate this.

The features of the geology between Bara Nanda and Buruhatu are not accurately delineated on Jones's map. The conglomerate does not continue across from Bara Nanda to Buruhatu. At Bara Nanda it rests on granite to the east and on quartzite to the south. The conglomerate on the quartzite is silicified, probably from proximity to a fault along the quartzite which has let down a very small outcrop of conglomerate on the south slope of the quartzite. In the stream immediately to the south there is a tongue of granite exposed between the quartzite and the lava, and the granite may be seen intruding into the lava. Also, there is a small section here, in a branch of the *nadi*, of a 6-inch bed of horizontal silicified sandstone-conglomerate resting on granite containing included blocks of quartzite.

The outlier of conglomerate at Buruhatu increases to at least 20 feet in thickness, in consequence of the gently undulating nature of the exposed old lava surface in Kolhan times. West of Bara Nanda a thin bed of finely banded fine-grained sandstone occurs

at intervals along the edge of the lava, but just as near Siringsia it occasionally thins out, so here also it is absent in many places, and shales rest directly on the lava. However, in some places, a thick cover of alluvium may obscure sandstone. Some jasper and chert is to be seen along the upper surface of the lava here. In some places little promontories of lava project above the horizontal shales.

South of Itar Baljori horizontal fine-banded shaly beds rest directly on the lava along its northern boundary. They are highly chloritic and apparently represent a fine wash from the lava. Thin siliceous beds grade to sandstone, and oxidation of the chloritic material gives it a fine-banded brownish red colour. It is not easy to judge where to class it as sandstone and where as shale for purposes of mapping. Further south it spreads horizontally over the lava as a thin bed.

About 1½ miles south of Kotgarh, where the road to Noamundi crosses the Barnal Lor, an excellent section is exposed in the bed of the stream just east of the road. Horizontal and gently undulating flaggy purple sandstones rest on the lava. The base of the sandstone, filling in hollows in the lava surface, is a peculiar soft rock, in part a wash from the lava but containing also angular and sub-angular grains of quartz, chert, jasper, iron-ore and shaly material. It contains thin beds of hematite and also boulders of hematite. Above, is the typically flaggy sandstone, varying from grey to purple in colour, and in places high in hematite so as to become really an iron-ore, and occasionally ripple-marked. Some 6 to 7 feet from the base there is a coarse soft conglomerate of lava, jasper and quartz pebbles in a lateritised sandstone matrix. A thin quartz vein cuts across the sandstone and conglomerate. Although horizontal in the stream bed, the base against the lava in the south bank has been tilted at 45° with apparently some differential movement. Immediately below the sandstone the lava has been almost completely oxidised to a depth of several feet, but here and there less altered material remains; even in the completely oxidised material traces of amygdules can be seen occasionally. Right at the contact the lava has altered to a massive hematite, and seams of hematite occur along what were originally joint planes in the less altered lava. This hematite is obviously the source of the detrital hematite in the overlying sandstone. Slickensided surfaces in the hematite indicate a certain

amount of movement. The alteration of the lava between Kotgarh and Noamundi, where it underlies the conglomerate, has been already described.

Along the boundary there are, in places, fine hematite-sandstones, approaching iron-ores, or conglomerates consisting of pebbles of iron-ore, quartz and jasper, in a hematite cement, the cement partly replacing the jasper. Sometimes Kolhan shales come in direct contact with the altered surface. At other places lateritisation of both shales and altered lava makes the actual boundary a little obscure. Such lateritic material may be manganiferous, as to the south of Kumirta.

We now approach the critical section on which the new determination of the sequence is securely founded. So far, the above description has been in conformity with Jones's mapping and interpretation (except that the purple sandstone is not intruded by the granite), as the sandstone-conglomerate had been mapped up to Noamundi mine—but not further. It continues westward, however.

Sweeping around from Pachaisai to Toretupa there is a small escarpment facing south, of typical purple sandstone (quartz, jasper and iron-ore grains rimmed with hematite, and with quartz cement), sometimes conglomeratic at the base, overlying lava—the latter is usually hematitised below the unconformity and contains much jasper. North-east of Mahudi there are two small outliers of the conglomerate forming hillocks above the lava—these conglomerates contain abundant pebbles of iron-ore and banded-hematite-quartzite and their debris has been collected and sent to the smelter as iron-ore. In the escarpment at Toretupa the sandstone-conglomerate dips gently north below flat-lying shales. This relation persists through Sangramsai village, the sandstone having now gradually given place entirely to conglomerate which is about 20 feet thick where it crosses the stream north of the railway line and west of the village, and dips gently north at 5°-10°. West of the stream it covers the northern slope of the hill north of the line, then, about 300 yards west of the stream, a fine section is exposed in the railway cutting. In this section it overlies a highly altered hematitic material, now in part phyllitic, some of which may be after lava but most appears to have been originally fine tuff. The old erosion surface between the conglomerate and the underlying rocks is clearly seen. The conglomerate is hard,

massive, and well-jointed, and quartz veins cut across the bedding. The pebbles of banded-hematite-quartzite, jasper, chert, quartz and iron-ore are in a well-bedded matrix of silicified sandstone.

The conglomerate, dipping gently north, crosses the railway line. Along the fireline on the hillside above the next cutting, and below the laterite on the hill-top, the southern boundary of the conglomerate, striking east-west, is seen to overlie banded-hematite-quartzite which here strikes north-west dipping at 40°-50° to the south-west. The railway cutting below exposes Kolhan shales (phyllitic) which immediately overlie the conglomerate—in a *nadi* beneath the embankment, just east of this cutting, the shales may be actually seen resting directly on the conglomerate. The dips are usually gently north, but locally the shales may steepen even to 30°. The first signs of more acute folding in the Kolhan rocks now become evident and in consequence of this folding a tongue of conglomerate crops out north towards Merelgara and extends towards Baljori. However, still following the railway line, the conglomerate crops out as a wide north-sloping pavement along the southern side of the embankment south of Merelgara, where the conglomerate boulders attain huge dimensions, consisting of great angular blocks of banded-hematite-quartzite up to even 5 feet across, obviously representing an old scree deposit on the banded-hematite-quartzite, which here must have projected as a cliff promontory on the old shore line.

In the railway cutting north of Noamundi village the character of the conglomerate again changes. For the most part it is now a white sandstone-quartzite at least 25 feet thick, with, however, beds of conglomerate 3 to 4 feet thick. Upwards, it grades through finely bedded flaggy felspathic sandstones interbedded with phyllitic shales, to purplish coloured phyllites. The dip is gently undulating but easterly, and towards the west end of the cutting the sandstone-conglomerate is seen to rest on westerly dipping Iron-ore Series phyllites which soon turn to a southerly dip of 30°, the sandstone persisting horizontally along the top of the cutting, resting on the truncated phyllites (fig. 7). The truncated ends of the

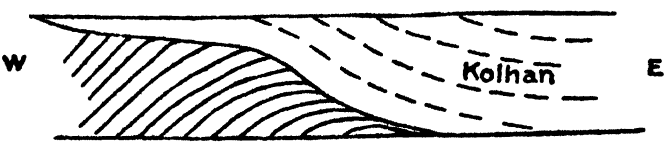


FIG. 7.—Section in railway cutting north of Noamundi village.

phyllites have been dragged over at the bend in the sandstone, as would be expected. The Iron-ore Series phyllites here are purplish in colour, sometimes mottled white, rather more massive perhaps than the overlying well-cleaved Kolhan phyllites, but otherwise the two phyllites are indistinguishable.

To the south the conglomerate crosses the road and occurs on two hills west of Noamundi village, where it varies from an iron-ore conglomerate, through a sandstone-conglomerate to a fine sandstone-quartzite. The iron-ore conglomerate consists of hematitic pebbles in a matrix of hematite, and the debris from this has been mined as iron-ore.

The conglomerate strikes north from the railway cutting towards a small outlier of banded-hematite-quartzite forming a hill to the south-east of Baljori, and joins up with the conglomerate from Merelgara, thus enclosing an area of Kolhan phyllites. Immediately to the south of the above-mentioned hill, an excellent anticline is exposed in the conglomerate. The hill, during deposition of the conglomerate, was undoubtedly a promontory or small island. Although no conglomerate is actually seen to crop out at its base, conglomerate debris is plentiful around it.

On the ridge to the south-west the conglomerate is often coarse, but frequently it consists of small pebbles of banded-hematite-quartzite and jasper, about the size of a pea, in a fine sandstone-quartzite matrix. At the ridge top it is often an iron-ore, of iron-ore pebbles in a detrital hematite matrix, or even a fine "grit" of hematite grains cemented by hematite. Sometimes it is a fine-bedded brightly coloured sandstone-quartzite, containing fine grains of jasper and chert—with silicification this latter rock becomes cherty in places and very similar to a fine banded-hematite-quartzite.

Perhaps the best exposure of the sandstone and conglomerate occurs along the Kantoria *nadi* to the west. Here it attains a thickness of at least 250 feet, even allowing for the gently undulating nature of the dips. On the ridge to the east it rests on a bed of white chert, which is also found in the stream. Iron-ore Series phyllites just to the south are highly contorted, but further south still their dips are westerly. The sandstone-conglomerate is conglomeratic at the base with boulders up to 12 inches diameter of chert, jasper and a buff coloured sandstone-quartzite, all in a buff sandstone matrix. Descending the stream with the dip for half a mile, alternating beds of sandstone and conglomerate are

passed over, usually well-bedded and often flaggy, the pebbles becoming rather smaller higher in the sequence.

West of the stream the general strike of the base of the Kolhan Series turns sharply north, but at the turn the base shows close-folding. A close-folded syncline strikes south across the railway line and is well exposed in a cutting. The isoclinal folds can be followed and the sandstone-conglomerate is seen to be strongly sheared. Beds of phyllite are present, but owing to the strong shearing it is not certain whether these are of the Kolhan or the Iron-ore Series. This syncline dies out before reaching the road to the south. On the hill slopes north of the line, however, thin pinched-in bottoms of the sandstone synclines can be seen in the Iron-ore Series phyllites, and mapping here can only be diagrammatic.

The main outcrop of conglomerate covers the eastern slope of the ridge south of Param Baljori, and, in a prospecting trench on the ridge-top, it is seen to rest on Iron-ore Series purple phyllites. The conglomerate here is of hematite pebbles and is almost an iron-ore. It is only about 50 feet thick—a sudden diminution in thickness from the 250 feet in the stream to the east. However, it has been noticed that rapid changes in thickness and lithology are characteristic of this basal bed. The dips now steepen, sometimes up to 70°, and in the overlying phyllites only cleavage dips can be recorded. Further north such local steep dips become common. West of Param Baljori yet another syncline of sandstone-conglomerate projects south from the main strike.

To the north, the upper part of the sandstone-conglomerate is often high in iron, forming sometimes an iron-ore conglomerate. The dips of the basal bed are rolling, but usually flat. Half a mile N. N. E. of Kantoria, the dip is vertical for a short distance and, to the east of this point, a pinched anticline of the upper ferruginous conglomerate of the basal bed pitches north below the Kolhan phyllites. North-east of Kantoria a silicified tuff breccia, with highly limonitised amygdaloidal lava, immediately underlies the sandstone.

The sandstone was followed close to the northern edge of the map, around Heselberel Buru, where it is again of considerable thickness but with rolling dips, and overlies phyllites which dip north-west at 70°. It varies from fine to coarse grained white sandstone-quartzite, often felspathic and sometimes conglomeratic, with quartz pebbles dominant but with some jasper. Its eastern or upper

edge is again an iron-ore conglomerate. To the east, the Kolhan phyllitic slates are ferruginous.

Where mapping of the conglomerate was finally stopped, the base of the Kolhan Series strikes parallel with the general trend of the Iron-ore Series, with the result that signs of the unconformity at its base are now obscure.

The sandstone-conglomerate, with its overlying impersistent limestone, and shale, has, then, been followed for some 60 miles south-west from Chaibasa. It is almost continuously persistent, except for a few short distances within which the strike of the immediately overlying shales can be followed. As it happens, however, the places where it thins out are immaterial to the demonstration of the proof of the existence of the two series, and the conglomerate is best developed where it is so essential to that proof. It has been shown that the conglomerate overlies in succession granite, lava, tuff, banded-hematite-quartzite and phyllite. Where it contains the coarsest pebbles of banded-hematite-quartzite and jasper there it immediately overlies outcrops of these rocks, whilst its fine sandstone facies is best developed over granite, lava and phyllite. This is what one would expect, the banded-hematite-quartzite forming promontories on the old shore line, against which coarse screes would be formed, pebbles diminishing along the shore line away from these promontories. Where flat lying, over granite and lava, the sandstone is usually purple in colour, whereas over phyllite, where the dips are usually steep, the colour is white or buff. It is not at all improbable that the hematite cement is due not only to detrital hematite from the denuded rocks, but also in part to solutions since deposition. Over granite, lava, and banded-hematite-quartzite, the dips of the Kolhan Series are horizontal or gentle, but over phyllites they immediately become steep and the Kolhan Series is closely folded. The granite, fresh lava and banded-hematite-quartzite resisted further folding, whereas the Iron-ore Series phyllites were still able to yield to post-Kolhan earth movements and the Kolhan Series, resting on them, became infolded with the plastic basement.

Outlying conglomerates.

The increase in amount of folding along the western edge of the main Kolhan basin has been already noted. This close-folding persists further west, and the basal Kolhan bed has been folded

down here and there within the area of the Iron-ore Series, as small outliers.

West of the main boundary, north of Kantoria (22° 12′: 85° 27′), there are several small outliers of white Kolhan sandstone, surrounded by Iron-ore Series phyllites, and usually occurring on the hill-tops. On the ridge-top about 1½ miles N. N. W. of Kantoria, there is one interesting little outcrop consisting of a layer of conglomerate, no more than 12 inches thick, which dips gently north and rests unconformably on steeply dipping purple phyllites and tuffs of the Iron-ore Series. The debris from this conglomerate, now almost completely denuded, is strewn down the hill-side. About half a mile west of this occurrence there is an elongated outcrop of sandstone, varying to conglomerate, which strikes S. S. W. for over two miles. In places it is sheared, and in others, particularly on the eastern side, it is seen to overlie the Iron-ore Series phyllites and lava. It represents a narrow syncline, overthrust in places.

At the south end of a railway cutting about half a mile south-east of Thakura (22° 13′, 85° 24′) a conglomerate, containing banded-hematite-quartzite, jasper and quartz pebbles, is exposed. It is apparently a sharp syncline much disturbed on its north-west side. At first the possibility was considered that it might join up along the strike with the elongated outcrop just described, but careful traversing of the hillsides failed to bring to light continuity between the outcrops. Much care was taken over this particular locality as there was the possibility that this sandstone-conglomerate bounded another basin of Kolhan phyllites to the north.

Immediately north of Diriburu village (22° 12′, 85° 25′) a small patch of conglomerate, containing banded-hematite-quartzite, jasper, chert and iron-ore pebbles, overlies an altered lava. Other patches of white sandstone occur in the hills further north.

The most important outlier of the Kolhan basal bed is at Jhiling Buru, south of Gua, where the conglomerate consists of hematite pebbles in a hematite matrix, and is so rich in iron that it is mined as an iron-ore. Within the quarries, the bed is seen to be closely folded. On the south-eastern side of the ridge, it rests unconformably on an altered and sheared lava and phyllite; on the western side, on a white and grey chert, often brecciated. Along

the road, just south of Gua village, the conglomerate is seen to rest horizontally on an eroded surface of red jasper. On the north side of Jhiling Buru, and across the river, where it also rests on jasper, it has changed to pebbles of banded-hematite-quartzite, jasper and chert in a ferruginous sandy matrix. From immediately south of the power house the conglomerate bed can be followed to the west across a stream and along the northern face of a ridge. On the east side of the stream, it overlies sericitic schists and chert, the schists having two cleavages. On the west side of the stream the conglomerate overlies mottled and brecciated cherts, and dips to the north at 40° below shales which are seen to rest conformably upon it. It contains a little manganese here in addition to iron. Further west it swings to the south-west, dipping north-west, and here it becomes lost below the hill debris. It will be noticed that this last dip, where lost, is parallel to the Iron-ore Range and is below the phyllites which underlie the banded-hematite-quartzite of the range. Unless we are to assume that all the phyllites below the banded-hematite-quartzite of the range are of the Kolhan Series, we must admit the existence of strong overthrusting here, amounting to several hundred feet of differential movement. To the south-west the Iron-ore Range is offset and in the saddle between the offset ridges outcrops of phyllite and lava occupy presumably an overfolded anticline. It is suggested that the proposed overthrust is connected with this overfolded anticline.

On the ridges to the south of the Jhiling Buru mine workings some debris of conglomerate represents denuded outcrops, associated with some lateritic manganese deposits over phyllite and chert.

On the east side of Jhiling Buru, the conglomerate is seen to underlie shales. Immediately overlying it is a 6-inch bed of greenish and reddish, hard, almost flinty shale which breaks with a hackly fracture—this was also found overlying the conglomerate at the foot of the ridge to the north-west of Jhiling Buru. Along the river bank the well-bedded arenaceous shales, with lenticular bands of fine arkose-conglomerate, are gently folded and are quarried for building material. As the phyllites and lavas on the east side of the river are of the Iron-ore Series type, there must be a N.N.W.-striking fault along the river—the necessary downthrow is not more than 50 feet.

From the eastern side of Jhiling Buru, the conglomerate can be followed in a south-easterly direction. It is now much thinner, perhaps 15 feet, and its character has again rapidly changed to a buff coloured sandstone-quartzite with small occasional pebbles of banded-hematite-quartzite, jasper and white chert. It overlies lava. Crossing the Karo river it becomes interbedded with shale bands on the eastern bank, then turns almost due south as a well-defined bed of conglomerate, dipping at first steeply east, then flattening to horizontal, and then, in the stream bed just north-west of Bokna, dipping north-west and overlying phyllites of the Iron-ore Series on its eastern side. Just west of this last section the conglomerate is highly sheared, a characteristic which persists to the south. The only explanation which satisfactorily fits these relations from Jhiling Buru southwards, is that a fault on the east side of the conglomerate towards the north crosses the conglomerate at an acute angle at about the place where it lies horizontally, and then continues as a shear zone in the conglomerate further south.

On the map, a wide zone of conglomerate has been shown between Bokna and the Karo river. North of the road the ridge is thickly covered with debris, and, on the western side of the hills, with laterite which is often sufficiently high in manganese to be mined as manganese-ore. But abundant conglomerate debris, often an iron-ore conglomerate, is scattered over the laterite and, here and there, folded outcrops of it may be seen. Along the road-cutting near the Karo river the west side of the conglomerate is considerably sheared, apparently by overthrusting from the west—the shearing persists along the strike to the tributary stream some half a mile south of the road, where the conglomerate ends. It is obvious that the whole of this zone is closely folded and sheared and that underlying phyllites of the Iron-ore Series are probably folded in with the conglomerate below the thick mantle of soil and debris. The south-eastern extremity of this conglomerate, represented by a coarse sandstone, rests almost horizontally on lava to the south, the east side being apparently faulted.

On the same line of strike there is a small outcrop of sandstone half a mile further south, west of Uliburu.

North-east of Bokna a flat syncline of conglomerate and sandstone occupies the top of the ridge striking N. N. E. The lower 15 to 20 feet are of conglomerate, the upper beds are of fine

sandstone. At the north end sandstone-conglomerate rests on lava, and at the south end on steeply dipping phyllites and altered lava. The dips of the sandstone are at a flat angle inwards towards the centre of the ridge and the underlying rocks crop out within 50 feet of the top.

Spencer has already described[1] the band of conglomerate which strikes S. S. E. from just west of Jamda station, where it underlies phyllites, to the Nalda *nalla* and along the west side of the ridge east of Uliburu. Spencer did not, however, indicate the structure of this bed at its northern end where it underlies purple phyllites. These phyllites are finely fragmental and may possibly be tuffs. Just to the north of the road, in the railway cutting, they are seen to be folded into a crumpled anticline, with a sharp small anticlinal cap of the sandstone peeping up above the bottom of the cutting towards the west end. To the north-east the rocks are covered by thick laterite, and only one little patch of conglomerate is seen again just north of Jamda station. Spencer remarks that the dip of the conglomerate is regular where it crosses the Nalda *nalla*, but I find that the dips at this point are anything but regular, some being north-west, some north-east, although the general trend of the strike is N. N. E. The actual thickness of conglomerate is, therefore, only a fraction of that indicated by Spencer. On the hill to the south it is covered by laterite, but outcrops are again found on the ridge east of Uliburu. Conglomerate is well developed immediately on the east side of the village and again near the ridge-top. Cropping out between the two there is a fine banded rock which, at first, was mapped as banded-hematite-quartzite. On closer examination, however, this was found to consist of well-rounded grains of iron-ore, jasper, and chert with a few of fine quartzite, in a matrix of fine chert. Some of the beds are mainly of hematite, others of white chert. Under the microscope the chert bands are seen to contain numerous small hematitised rhombohedra which were probably originally carbonate. The rock is apparently a chertified sandstone-grit which exactly simulates banded-hematite-quartzite. The western side of these Kolhan shales and sandstone-conglomerate between Jamda and Uliburu is presumably faulted. Spencer records another patch of conglomerate west of Jhargaon (22° 03′, 85° 23′).

[1] E. Spencer, *Trans. Min. Geol. Inst. Ind.*, 26, p. 323, (1933).

There is little doubt that further outliers of this basal conglomerate, and possibly of its accompanying phyllites, will be found. It is quite conceivable that the thick mantle of alluvium and laterite in the valleys between the iron-ore ridges may conceal quite extensive areas of Kolhan rocks.

THE SANDSTONE-CONGLOMERATE IN KEONJHAR.

Wide outcrops of sandstone extend south along the eastern border of the iron-ore area from near Bhondgaon (22° 05′, 85° 35′) in Singhbhum into Keonjhar State. This part of Keonjhar State, shown on the map which accompanies Jones's memoir, was surveyed by Dr. Krishnan, who naturally interpreted his mapping on the basis of the sequence which had at that time been accepted as conclusively proved by Jones's sections. The sandstones in Keonjhar are shown by Krishnan to extend westward, along transverse valleys, around the banded-hematite-quartzite at Churia Pahar (22° 01′, 85° 28′), north-west of Surguturia (21° 59′, 85° 27′) and south of Gurubera (21° 58′, 85° 26′), just as would be expected if these flat-lying sandstones should underlie the Iron-ore Series. Such a relation was inconsistent with the now known fact that the Kolhan conglomerate rests on the banded-hematite-quartzite, so that there was the possibility that these outcrops of sandstone-conglomerate in Keonjhar might be of an older lower Iron-ore Series sediment. Accordingly the critical places were examined. The sandstones were found not to persist up the valleys as had been previously shown on the map. There is certainly faulting in places along this boundary—faulting which I believe is somewhat recent—but there is sufficient evidence to confirm that the sandstone rests on the granite, lava, phyllite and banded-hematite-quartzite, each of which it overlaps in turn. Its dip is undulating, but, quite commonly, in consequence of faulting, the dips even close to the boundary may be gently westward, towards the older rocks, a feature which was consistent with the old interpretation and which, therefore, gave no clue to the latter's incorrectness.

Near Bhondgaon, Kondra and Dudwan the rock is a typical flaggy purple sandstone varying to a fine conglomerate with the usual chert, jasper, banded-hematite-quartzite, iron-ore and quartz pebbles, but further south, and spread over a wide area, it is a light coloured massive bedded sandstone, only slightly silicified, containing mainly grains of quartz, a little orthoclase and chert, and with

often a sericitic matrix. Small pebbles of quartz and chert occur occasionally.

Around Bhondgaon and to the south the sandstone rests partly on lava and partly on granite. West of Kondra (22° 03′, 85° 31′) a small patch of conglomerate rests horizontally on granite; on its western side dips are to the west but it is faulted, and in places sheared, against lava. West of Dudwan (22° 01′, 85° 28′) the sandstone is either horizontal, or dips gently towards the east down the slope of the north-east spur of Churia Pahar, and is seen to rest on the lava. From here the boundary turns abruptly south of S. S. E. and, as seen on the south side of Churia Pahar, it is clearly faulted, the dips being gently towards the south, along the direction of the boundary. A steep *nalla* marks the boundary down the southern face of the hill, the east side of the *nalla* being sandstone and the west side chert and banded-hematite-quartzite.

On the eastern slope of Bara Parbat (22° 01′, 85° 27′), about one mile west of the main sandstone boundary, there is an outcrop of sandstone and conglomerate which rests on the banded-hematite-quartzite and dips to the east down the slope of the hill. The conglomerate is of coarse iron-ore pebbles in an iron-ore matrix. In places it is fine grained and finely bedded, simulating normal laminated ore. Conformably overlying it at one place is white sandstone, typical of the Kolhan sandstone in this vicinity.

South of Banspani Pahar (22° 00′, 85° 27′) sandstone dips to the south-east, away from phyllitic rocks which may be sheared altered lava. A short distance from the boundary, the dip of the sandstone becomes horizontal and approaching the river gentle westward dips up to a maximum of 10° are observed.

Around Surguturia (21° 59′, 85° 27′) there is more faulting and, also, laterite tends to obscure boundaries, but the gently dipping or horizontal sandstone is in contrast with the steep dipping banded quartzite.

In the saddle west of Jajang (21° 56′, 85° 26′) the sandstone rests on chert, and at the border is more or less horizontal with a tendency to dip east.

Kolhan limestone.

According to the analyses given by Jones and also that of No. 54/501 on page 362, the Kolhan limestone is quite low in magnesia, but insolubles are rather high. There are, in fact, all gradations to phyllitic

shale. The limestone is usually thin bedded and flaggy, a structure which the Hos have found to be eminently suitable for its use as burial slabs. Its colour is variously pink, grey, white, and even greenish, and it may contain thin chert lenticles of the same colour. Thin laminae of phyllitic shale are abundant. Ripple marking has been observed on the bedding planes. Chlorite and sericite are usually abundant, and the rock has a phyllitic sheen, with a well-developed cleavage parallel to the bedding. The rock has been more recrystallised than has been thought previously. Small quartz veins traverse the limestone in places.

The limestone usually immediately overlies the basal sandstone-conglomerate, although a thin layer of shale intervenes between the two in places. The thickness of the limestone is variable; in the hill south-east of Kundbera (22° 30′, 85° 47′) it is at least 30 feet thick, but perhaps it attains its greatest thickness near Rajanka (22° 26′, 85° 44′) where it has been prospected by the Tata Iron and Steel Co. It sometimes thins out completely and is not found west of Jagannathpur (22° 13′, 85° 39′). It is suspected that certain calcareous shales to the west, shown on Jones's map, represent the same bed.

At the north end of the Kolhan basin, south of Chaibasa, where the dips of the bed are flat, the limestone spreads over a wide area, undulating below the phyllites. From the map it might appear that, here, it is separated from the basal sandstone by quite a considerable thickness of shale, but such is not the case. There is, apparently, much faulting in this vicinity and, in addition, there has been a remarkable alteration of the rocks by hot solutions.[1] These have completely leached away the limestone which immediately overlies the basal sandstone along the eastern edge of the basin between Surjabasa (22° 28′, 85° 47′) and Madkamhatu (22° 32′, 85° 48′), removing all $CaCO_3$, leaving only an incoherent sericite-quartz-schist which has retained the bedding of the original limestone and in which thin chert lenticles remain. At the same time the manganese oxide of the underlying rocks has been leached. and has been concentrated in this altered material and in the sandstone, the latter also being occasionally altered to a fine friable sericite-quartz-schist. The manganese-ore occurs in these altered rocks as thin lenticles parallel to the bedding, or as nodules. The

[1] J. A. Dunn, *Rec. Geol. Surv. Ind.*, 74 (4), pp. 467-473, (1940).

early stages of this alteration can be seen in occasional outcrops of limestone in which the removal of $CaCO_3$ has left, in certain layers, a porous sericite-quartz rock. It is probable that much of the very pronounced folding which is present in the adjacent phyllitic shales, is due, in part, to collapse over leached out areas of limestone.

Kolhan shales and phyllites.

Jones's description of his "lower shales' is largely that of the Kolhan shales and phyllites. They are sometimes quite phyllitic, even where they are horizontal or flat-dipping, as near the south of Chaibasa. Here they have been permeated by hot solutions which left behind a swarm of quartz veins, and the rocks have a remarkable phyllitic sheen, notwithstanding the gently undulating nature of the beds and the normal absence of close folding. Where associated with outliers of conglomerate within the area of the Iron-ore Series, and where the dips are steep and the cleavage oblique to the bedding the phyllitic texture is very apparent. Cleavage in the south-west portion of the basin may completely obliterate bedding.

Usually purple in colour these rocks are, however, often grey, buff or even greenish and sometimes may be slightly mottled. Although the purple colour of many of the shales is inherent since deposition of these beds, it is, in other cases, due to later staining by iron oxide. Frequently such staining takes place during weathering and a rock which may be purple on the weathered surface may be grey or buff when fractured.

The typical shale or phyllite consists of a fine dense argillaceous material, often sericitic, which may or may not be stained by Fe_2O_3. These rocks are commonly finely bedded. Immediately overlying the basal sandstone the beds may become more arenaceous and grade through arenaceous shale to shaly sandstone. The phyllitic shale, which overlies the Kolhan sandstone west of Jamda railway station, consists of fine grains of quartz, chert, iron-ore and muscovite in an indeterminate rather ferruginous matrix—this may be a tuff or a somewhat arenaceous phase overlying the sandstone.

Along the edge of the main Kolhan basin south from Kundbera (22° 30′, 85° 47′) and around to north of Noamundi village, the

shales are consistently horizontal or dip gently inwards from the border up to a maximum of 10°. From Noamundi northwards the dips steepen and the close cleavage, which usually obscures the bedding, is often vertical.

Between Chaibasa, Nimdih (22° 30′, 85° 46′) and Kelendeh (22° 29′, 85° 48′), the phyllitic shales, although in places almost horizontal, are frequently steeply dipping and show unusual folding and even close contortion. One such zone, extending N. N. E. from Nimdih, is apparently connected with considerable faulting. Other areas of contorted phyllite, north of Kelendeh and around Madkamhatu (22° 32′, 85° 48′), cannot be so simply explained; here the phyllites are riddled with quartz veins and it is not at all improbable that the disturbance is due to the removal of originally underlying limestones in solution.

V. ANOMALOUS AREAS.

Before completing this description of the Kolhan Series, two areas may be noted, within which shales and sandstones possess anomalous characters as compared with adjacent normal beds of the Kolhan Series.

From Chaibasa to Noamundi the main basin of Kolhan rocks is relatively undisturbed, dips usually being from horizontal to gently north-westward. However, north of Hat Gamaria and east of the main Kolhan basin there is a local area in which shales and sandstone-conglomerate have been highly disturbed, apparently by simple normal faulting. Although elsewhere no Newer Dolerites have been seen to penetrate the base of the Kolhans, here dykes have ascended the faults and spread along the bedding as sills, indurating the adjacent shales. The question is—are these shales and sandstones to be grouped as Kolhan, or are they older? The boundaries are largely faulted, but wherever the basal sandstone-conglomerate can be seen it appears to rest directly on the granite and there is no evidence of intrusion. The western side of the faulted area is bounded by typical fine-bedded horizontal Kolhan purple sandstone, and the basal conglomerate of the disturbed area joins up with it. The curious feature is the sudden remarkable change in lithology of this basal bed in the disturbed area. Instead of being a fine-banded purple sandstone, it is either a conglomerate or a massive bedded white or brown sandstone which, further east, becomes an arkose of great thickness.

Around Chaibasa is another anomalous area. Immediately to the west of the town and overlying altered lava-schist, granite and phyllite, there is a group of rocks consisting of fine sandstone, dolomite and shale which, lithologically, are utterly different from the adjacent undoubted Kolhan rocks. The nearest Kolhan basal purple sandstone is only 400 yards away, but the sandstone under discussion has none of that typical colour which had been so characteristic for at least 25 miles. Further north, there is an arkose which grades to a sericite-quartz-schist exactly similar to sericite-quartz-schist inclusions in the granite. The calcareous rock, which overlies a 2-foot bed of sandstone to the west of Chaibasa, is also entirely different from the Kolhan limestone only ½-mile to the

south which had retained the same character for 25 miles. The dolomite here is a fine dark grey massive rock possessing none of the fine phyllitic bedding so characteristic of the Kolhan limestone. Fine-bedded sandstones and shales overlie this dolomite, whereas no sandstones have been observed to overlie the Kolhan limestones to the south. The same dolomite crops out just to the north of Chaibasa at Putada springs. An analysis of this dolomite is given in Table 2, along with one of the Kolhan limestone to indicate the wide difference in composition. It would appear that they are entirely different rocks and should not be correlated. None of the analyses of Kolhan limestone yet made has shown a high MgO content. Into this group, north and west of Chaibasa, Newer Dolerite dykes also intrude.

TABLE 2.

—	54/504 S. of Basakuti.	54/516 Putada springs.
SiO_2	22·10	2·50
Al_2O_3	8·51	1·66
Fe_2O_3	0·39	0·24
CaO	35·80	32·69
MgO	0·72	15·96
Na_2O	1·34	0·88
K_2O	0·32	0·13
MnO	0·84	Trace.
Loss on ignition	30·13	45·52
TOTAL	100·15	99·58
Sp. gr.	2·75	2·88

Analyst—R. Dutta Roy

Stratigraphically the group west of Chaibasa occupies the same position with respect to the underlying lava-schist as does the Kolhan Series. However, in view of the remarkable sudden change in lithology, the beds under discussion cannot be correlated as Kolhan without reservation, and are probably part of the Iron-ore Series. It suggests that the Kolhan Series does not continue north of Chaibasa, and is faulted on it western side, south-west of the town.

VI. THE NEWER DOLERITE.

The Newer Dolerite dykes have been described by several authors[1], and further detail is unnecessary here. Although the dolerite is normally unaltered, I have noticed instances in South Singhbhum where it shows a certain amount of recrystallisation, presumably under pressure. The dyke-sills to the south of Nurda (22° 20′, 85° 44′) are in part altered to epidiorite. Such metamorphism of the Newer Dolerite is prevalent in Dhalbhum. The age of the Newer Dolerite dykes remains debateable. They have not, as yet, been found to intrude into the main basin of the Kolhan Series, where recently re-surveyed. Although intruded into the areas of anomalous sandstones and shales, described in section V, it is quite probable that these latter are not of the Kolhan Series, but belong to the Iron-ore Series. Hence there is no certainity whether the dolerites are pre-Kolhan or post-Kolhan. The continuation of the survey of the Kolhan basin to the west will decide this. In the past I have suggested that the Newer Dolerites may be Cuddapah, but I no longer have any opinions on the matter as the main reason on which I based the suggestion—degree of metamorphism—I believe is no longer valid. My later experience on Gondwana rocks within these granitic areas of Bihar, has convinced me that in post-Gondwana times there have been earth movements of a severity which would readily convert the dolerites into epidiorites. There is no evidence on which to date them. Their relation to the granite is similar to the relation of the post-Gondwana dykes of the coalfields and Central Provinces to their associated granites, and one is tempted to view favourably the possibility that these Newer Dolerites could also be post-Gondwana.

[1] J. A. Dunn, *Mem. Geol. Surv. Ind.*, LIV, (1929).
H. C. Jones, *Mem. Geol. Surv. Ind.*, LXIII, (2), (1934).
M. S. Krishnan, *Rec. Geol. Surv. Ind.*, 71 (1), pp. 105-120, (1936).

VII. QUARTZ VEINS.

There has been a tendency in the past to associate most of the quartz veins in Singhbhum with the Singhbhum granite. These veins have been formed, however, at several different periods.

The occurrence of quartz pebbles in the conglomerate which is interbedded with lava and tuff to the north-east of the Noamundi mine ridge indicates the occurrence of quartz veins in a series of rocks older than the Iron-ore Series, but not at present known in South Singhbhum.

The quartz veins in the Iron-ore Series which have given rise to pebbles in the adjacent Kolhan conglomerate are probably related mainly to the Singhbhum granite.

Quartz veins occur in the Kolhan sandstone-conglomerate and in the limestone, whilst, in places, the Kolhan phyllitic shales are swarming with veins and irregular replacement masses of quartz. They are, of course, much later in age than the veins associated with the Singhbhum granite, but there can be no certainty that they are related to the quartz veins which penetrate the Newer Dolerite dykes. No quartz veins have been found in the ?Tertiary grit.

VIII. ?TERTIARY GRIT.

The age of a certain grit which occurs in this area is unknown. It can only be said that it is much later than the Kolhan Series. From its friable and porous nature, with incomplete cementing of the quartz grains, one may suggest that its age is not great.

This rock is not now very widespread, as it has been almost completely denuded. Wherever bedding can be detected, it is horizontal. The widest outcrops occur on the ridge-tops south-east of Gundijora (22° 11′, 85° 30′), resting on gently dipping Kolhan shales. Other small outcrops overlying Kolhan shales occur at the west end of Gundijora village and half a mile to the south, and also on Halmad Buru (22° 13′, 85° 28′). A small patch overlies banded-hematite-quartzite to the east of Noamundi village, and, north of the workings on Noamundi western ridge, a little of the grit is associated with laterite. Finally, some debris of this rock was found overlying the granite and lava area to the north-west of Padampur (22° 07′, 85° 38′). Many of the sandstone outcrops in the Kolhan basin to the north, beyond the limits of the portion re-surveyed, are probably to be correlated with this grit.

The rock is always dark brown in colour and is made up mainly of sharply angular quartz grains, some of them showing crystal faces, in a ferruginous cement. It sometimes contains small pebbles of altered lava, jasper, iron-ore and quartz. In places it is a fine-grained rock with quartz grains less than 1 mm. diameter, but usually the grains average about 2 to 3 mm. diameter. Under the microscope the Fe_2O_3 coating around the quartz grains is seen to incompletely fill the pore spaces, leaving open interstices. The rock is always readily distinguishable from the other sandstones and quartzites in this area.

IX. CANGA.

The convenient name *canga* is applied to a more or less recent deposit, consisting of all kinds of water worn and angular boulders in a hard ferruginous matrix which is usually lateritic. Sometimes, adjacent to the main ore bodies, as on Noamundi west ridge, it may consist entirely of iron-ore boulders in a limonitic matrix, and is then mined as ore. On Noamundi west ridge the canga capping is well exposed in some cliffs, with deep caves at the base of the canga.

Canga may occur at various levels. Usually it is found along the river banks, sometimes just above the level of the stream, at others up to more than 20 feet above the stream. Cliff sections of this canga are almost continuously exposed along parts of the Karo river. This close relation to stream banks indicates that it is essentially a river deposit, and its occurrence at different levels is in consequence of renewed stream activity. Quite frequently the canga deposits along the stream banks are undercut by the current. It is not suggested that all of this material is of the same age, some along the Karo river just above water level is very recent, but other deposits, such as that on the top of Noamundi west ridge, may be much older.

Canga should not be confused with the loose "float ore" or hill debris which covers all of these hill sides. However, where this "float" is consolidated with laterite there is, perhaps, a gradation to canga.

X. LATERITE.

Laterite is widespread over rocks of the Iron-ore Series, especially south of the line connecting Noamundi, Jamda, Bokna and Gua. North of this line, rejuvenation of stream activity has removed most of the laterite which was at one time present there, except from some of the hill-tops. To the south, however, such rejuvenation of denudation is not as yet so acute, and laterite commonly covers the hill slopes from hill-tops to valley bottoms. In consequence of this, although outcrops of the underlying rocks are so well exposed to the north they are often deficient to the south, where there may be not the slightest clue to what is below the surface cover in many places.

The laterite is commonly manganiferous in the zones already described, pages 333-331, the manganese being derived from the rocks below. The greater part of the manganese-ore worked in Singhbhum and adjacent Keonjhar and Bonai is of lateritic origin, and overlies rocks of the Iron-ore Series. There are, of course, deposits of manganese in the Kolhan Series, such as those within six miles of Chaibasa, and also on the northern edge of the small plateau south of Baljori (22° 17′, 85° 45′) where lateritic manganese is found to overly shales of the Kolhan Series.

Laterite is more particularly widespread over the ferruginous rocks of the Iron-ore Series. Sometimes iron-ore grades to lateritic ore, which may be found not only at the surface, but also in patches at a little depth within the ore-body, depending presumably on drainage of surface waters.

It has been suggested to me that a "ropy" structure in laterite over lava indicates presumably a ropy structure of the original lava. Such "ropy" structure is found occasionally, however, in laterite overlying any rock and has no relation to rock structure.

[1] The title to Plate 6 accompanying the paper by Percival and Spencer, "Conglomerates and lavas in the Singhbhum—Orissa Iron-ore Series", *Trans. Min. Geol. Met. Inst. India*, 35 (4), pp. 341-363, (1940), is incorrect. It should read "Limonite, simulating the form of ropy lava." The specimen was kindly sent to the Geological Survey by Dr. Spencer.

XI. RECENT UPLIFT.

This hill region of the Kolhan and adjacent Keonjhar may be regarded as a southern extension of the Ranchi plateau, but which has, however, been subjected to considerable recent denudation. There are signs everywhere north of Jamda of recent rejuvenation of stream activity, whereas, south of Jamda, there are wide areas of relatively shallow valleys in which the streams are still running in alluvium and even laterite. The most abrupt change in stream activity is to be noted along the eastern edge of the banded hematite-quartzite hills extending south from Noamundi mine. Here, the steep easterly drainage is just beginning to rapidly remove the surface cover of deep alluvium in the saddles between the ridges. An excellent example of this is in the valley south-east of Banspani Pahar (22° 00′, 85° 27′), where a tributary stream to the Baitarani river is rapidly removing the thick soil cover, even exposing the roots of trees to a depth of several feet. This rapid removal of surface soil is not a result of deforestation, but is due to the rapid cutting back of the stream headwaters. Such rejuvenation is attributed to comparatively recent uplift, with differential movement along the eastern side of the iron-ore area.

XII. FUTURE MAPPING.

The main theme of this note has been the separation of the newer group, the Kolhan Series, from the Iron-ore Series. In consequence of this separation it is apparent that, if the whole area is to be mapped stratigraphically, it requires re-surveying. Within the main basin of the Kolhan Series there has been no difficulty in separating the two series, because the basal sandstone-conglomerate has provided such a well-defined datum, and where-ever it is absent on the eastern side of the basement the under-lying rocks are lithologically different from the Kolhan shales. However, on the western side of the basin, phyllites of the two series are similar and strike more or less parallel so that should the intervening basal sandstone thin out, or be removed by fault-ing, I doubt whether it would be possible to distinguish a boundary between the phyllites of the two series. Such difficulties have already been noted in the outliers of Kolhan rocks west of Jamda and south of Gua. Other difficulties would appear in this close-folded area should sandstone-quartzites make their appearance ac-tually interbedded with the Iron-ore Series phyllites—possibilities of the anomalies which might arise have already been pointed out in describing the rocks north of Hat Gamaria and around Chaibasa.

Wherever difficulties or doubts in interpretation may arise in mapping these rocks further north, the sections between Jagan-nathpur and Jamda should always be kept in mind. We have been fortunate in having such clear exposures of this unconformity in a part of the Kolhan rocks which is relatively undisturbed, and in being able to follow the unconformity into areas of severe folding.

LOCALITY INDEX.

SUBJECT AND AUTHOR'S INDEX.

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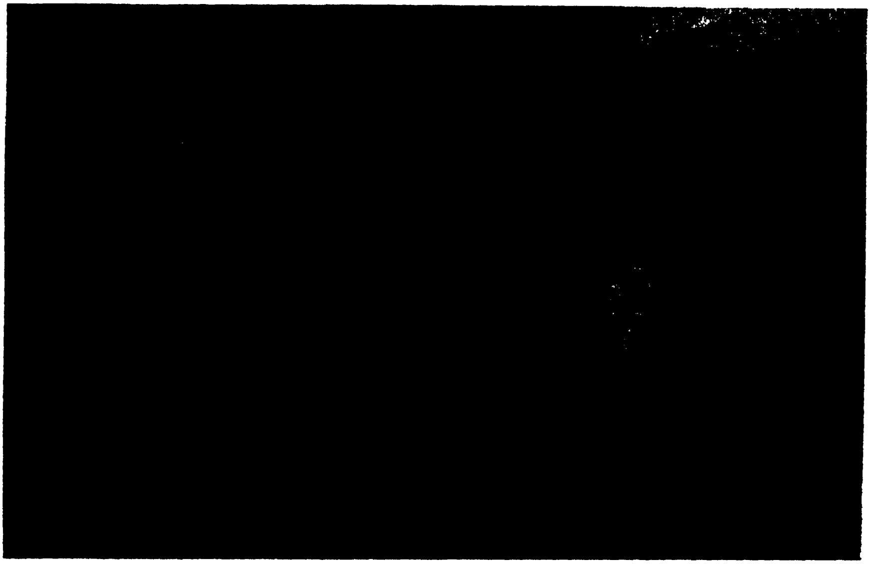

FIG. 1. KOLHAN BASAL SANDSTONE OVERLYING GRANITE AND HYBRIDS. PEBBLE BED AT CONTACT. RAILWAY-CUTTING, CHAIBASA. LOOKING WEST.

J. A Dunn, Photos. *G. S I. Calcutta.*

FIG. 2. KOLHAN PURPLE SANDSTONE OVERLYING IRON-ORE SERIES SCHISTS AND HYBRIDS. CHAIBASA CUTTING.

Memoirs, Vol. LXIII, Pl. 35.

FIG. 1. KOLHAN BASAL SANDSTONE OVERLYING TRUNCATED SCHISTS AND GRANITE. CHAIBASA RAILWAY-CUTTING. LOOKING EAST.

J. A Dunn, Photos. *G. S I. Calcutta.*

FIG. 2. MASSIVE KOLHAN CONGLOMERATE OVER "MOHUDI SHALE". PEBBLE SURFACE AT CONTACT. RAILWAY-CUTTING NORTH OF NOAMUNDI MINE. LOOKING SOUTH-WEST.

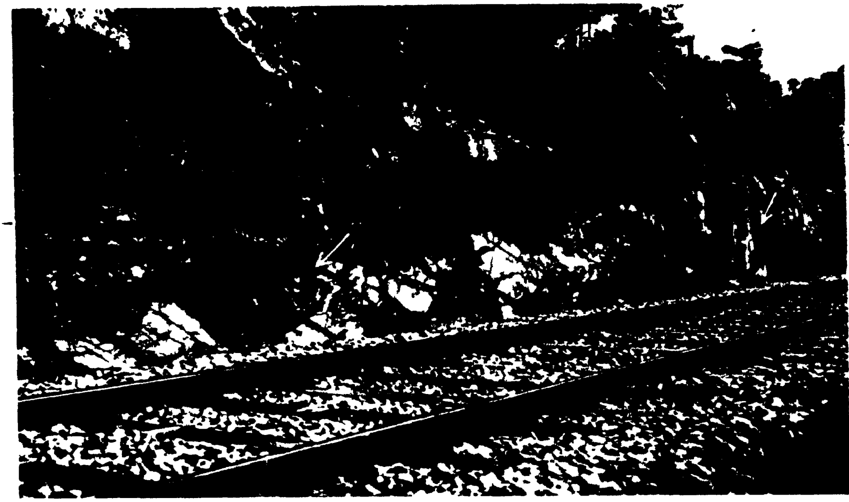

FIG 1 KOLHAN CONGLOMERATE OVER "MOHUDI SHALES". RAILWAY-CUTTING NORTH OF NOAMUNDI MINE. LOOKING NORTH-EAST.

J A Dunn, Photos *G. S I. Calcutta.*

FIG 2. KOLHAN SANDSTONE AND CONGLOMERATE OVERLYING IRON-ORE SERIES PHYLLITES. RAILWAY-CUTTING NORTH OF NOAMUNDI VILLAGE. LOOKING NORTH-EAST.

FIG 1 KOLHAN SANDSTONE AND CONGLOMERATE OVERLYING IRON ORE SERIES PHYLLITE RAILWAY CUTTING NORTH OF NOAMUNDI MINE LOOKING SOUTH EAST

J A Dunn Photos *G S I Calcutta*

FIG 2 CONGLOMERATIC IRON-ORE OVERLYING IRON-ORE SERIES CLAY AFTER LAVA JHILING BURU LOOKING NORTH